DAG-TM Concept Element 6
En Route Trajectory Negotiation
Operational Concept Description

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Preface

This report was developed from the referenced documents in order to conform to the required contents of an Operational Concept Description (OCD) as jointly defined by National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) Free Flight Project Office. The majority of the descriptive material has been taken verbatim from the referenced documents (and noted with square brackets around reference) available at the time of publication. Modifications have been made to add sections not in previous concept descriptions, to improve readability, and to reflect the most currently available information.

This approach to the development of this document was taken in order to remain faithful to the efforts that are presently being undertaken by the NASA Advanced Air Traffic Technologies (AATT) Project Office, the Tool Developers and the associated NASA AATT contractors.

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1. Scope

The Advanced Air Transportation Technologies (AATT) National Airspace System (NAS) Operational Concept Description (OCD) (to be published) documents current research and to provide concept guidance for all AATT projects. It was designed with the understanding that each project element would require a separate OCD of a subset or domain in the NAS in which a particular deficiency is addressed. This OCD is intended to provide guidance for Distributed Air/Ground-Traffic Management (DAG-TM) Concept Element (CE) 6 requirements development, to address and document how DAG-TM CE 6 fits into the overall NAS, and to provide a means to help transfer this technology to the FAA. It is consistent with the AATT Operational Concept for Air Traffic Management (ATM) (Reference 1).

1.1 Identification

This document applies to the DAG-TM CE 6 entitled “En Route Trajectory Negotiation”.

1.2 System Overview

<u>Purpose:</u> The purpose of DAG-TM CE 6 is to integrate flight deck (FD) and air traffic service provider (ATSP) automation to reduce controller workload, reduce flight path deviations, and to enable user preferred trajectories (UPT).

<u>General Nature of the System:</u> CE 6 will accomplish this purpose through:

- Basic data exchange between air traffic control (ATC) and an aircraft/user to support the calibration of air and ground decision support capabilities;
- User and ATSP negotiation for user-preferred trajectory changes:
    - The user formulates UPT (based on constraints) and transmits to the ATSP
    - The ATSP evaluates UPT for approval and amends constraints as needed
- Center/TRACON Automation System (CTAS)-Flight Management System (FMS) integration to facilitate:
    - Reduced datalink/CTAS input workload
    - Trajectory-based clearances and improved flight conformance

<u>History of System Development, Operation, and Maintenance:</u>

[The following history is a verbatim extract from Reference 2]

The current and projected growth in air traffic, delays, and inefficiencies has motivated the airspace user community to look towards concepts such as Free Flight (Reference 3) to increase operational efficiencies. The FAA, in collaboration with Industry, has responded with an evolutionary “spiral development” approach to the modernization of the U.S. NAS. This approach emphasizes the step-wise enhancement of current-day operations to achieve near-term benefits, with minimal programmatic risks, while laying the groundwork for longer-term progress. However, in order to achieve the mature state of Free Flight, potentially revolutionary methods of ATM will be necessary.

Current-day operations within the NAS may be characterized by the paradigm of “centralized” control. Much work has been done in the past to develop concepts for automating air traffic control, particularly in the area of en route operations (Reference 4). While most of the recent ATM research has been focused on decision support tool (DST) capabilities to enhance current-day operations (Reference 5), a significant portion of current ATM research by NASA is focused on longer-term goals. A key aspect of this long-term effort is the exploration of decentralized ATM techniques to maximize user flexibility (to plan and fly according to each operator’s changing or evolving needs), while safely meeting the operational constraints of a congested ATM system. Decentralized ATM techniques may enable growth in system capacity that would otherwise be limited. The approach is to facilitate distributed decision-making through the integrated design of air and ground systems. Technical feasibility and economic viability, for all relevant NAS stakeholders, are critical factors.

In January 1999, NASA formed a multi-disciplinary team to formulate an operational concept for decentralized ATM along with corresponding recommendations for supporting research activities. This team was comprised of 12 researchers representing the spectrum of NASA’s expertise in human factors, avionics/flight management, ATM DST engineering (en route / terminal / surface), communications, and benefits/safety assessment. An intense nine-month effort led to the formulation of the DAG-TM concept (Reference 6) and companion research plan (Reference 7).

Project Sponsor, Acquirer, User, Developer, and Maintenance Organizations: The NASA AATT Project is the sponsor of DAG-TM CE 6. The concept is being co-developed by NASA Langley and Ames Research Centers.

When implemented, the acquirer, user, and maintenance organization will be the FAA for any ground elements required and the airlines/users for any airborne elements.

Current and Planned Operating Sites: There are no current or planned operating sites.

Other Relevant Documents: Documents relevant to the DAG-TM CE 6 concept are found in Section 2.

1.3 Document Overview

This document is organized according to a format based on the IEEE J-STD-16-1995 standard. Descriptions of the OCD sections follow.

Section 1. Scope: This section contains a full identification of the system to which this OCD applies. It briefly states the purpose of the system; describes the general nature of the system; summarizes the history of system development, operation, and maintenance; identifies the project sponsor, acquirer, user, developer, and maintenance organizations; identifies current and planned operating sites; summarizes the purpose and contents of this document; describes any security or privacy protection considerations associated with its use; and lists other relevant documents.

Section 2. Referenced Documents: This section lists the number, title, version, date, and source of all documents referenced in this OCD.

Section 3. Current System/Situation: This section describes the background, mission, objectives, and scope of the current system/situation including applicable operational policies and constraints and a description of the current system/situation. The description includes, as applicable:

- The operational environment and its characteristics
- Major system components and the interconnections between these components
- Interfaces to external systems or procedures
- Capabilities/functions of the current system
- Charts and accompanying descriptions depicting input, output, data flow, and manual and automated processes
- Performance characteristics, such as speed, throughput, volume, and frequency
- Quality attributes, such as reliability, maintainability, availability, flexibility, portability, usability, and efficiency
- Provisions for safety, security, privacy protection, and continuity of operations in emergencies

In addition, a description of the types of users or personnel involved in the current system is included. This section also provides an overview of the support strategy for the current system.

Section 4. Justification for and Nature of Change: This section describes new or modified aspects of user needs, threats, missions, objectives, environments, interfaces, personnel, or other factors that require a new or modified system. It summarizes deficiencies or limitations in the current system that make it unable to respond to these factors. All new or modified capabilities/functions, processes, interfaces, or other changes needed to respond to these factors are summarized in this section. In addition, this section identifies priorities among the needed changes; changes considered but not included; the rationale for not including them; and, any assumptions and constraints applicable to the identified changes.

Section 5. Concept for a New or Modified System: This section describes the background, mission or objectives, and scope of the new or modified system and any applicable operational policies and constraints and a description of the new or modified system. The description includes, as applicable:

- The operational environment and its characteristics
- Major system components and the interconnections between these components
- Interfaces to external systems or procedures
- Capabilities/functions of the new or modified system
- Charts and accompanying descriptions depicting input, output, data flow, and manual and automated processes
- Performance characteristics, such as speed, throughput, volume, and frequency

- Quality attributes, such as reliability, maintainability, availability, flexibility, portability, usability, and efficiency
- Provisions for safety, security, privacy protection, and continuity of operations in emergencies

In addition, a description of the types of users or personnel involved in the new or modified system is included. This section also provides an overview of the support strategy for the new or modified system.

Section 6. Operational Scenarios: This section describes one or more operational scenarios that illustrate the role of the new or modified system, its interaction with users, its interface to other systems, and all states or modes identified for the system.

Section 7. Summary of Impacts: This section describes anticipated operational, organizational, and development impacts on the user, acquirer, developer, and maintenance organizations.

Section 8. Analysis of the Proposed System: This section provides a qualitative and quantitative summary of the advantages, disadvantages, and/or limitations of the new or modified system. Major system alternatives, the tradeoffs among them, and rationale for the decisions reached are also provided.

Section 9. Notes: This section contains general information that will aid the reader's understanding of this OCD. It includes an alphabetical listing of all acronyms and abbreviations and their meanings as used in this document, and a list of terms and definitions.

2. References

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3. Current Systems/Situation

3.1 Background, Objectives, and Scope

[Reference 8] With increasing traffic and congestion and a demand for improved efficiency and capacity in the NAS, air traffic controllers need automation tools and procedures to help them improve airspace efficiency and capacity while maintaining or improving their ability to maintain safe separation. Center radar (R-Side) controllers, who hold primary responsibility for aircraft separation in en route airspace, have a limited set of automation aides. Conflict Alert warns of possible traffic conflicts within a 2-minute time horizon. Though a useful safety net, Conflict Alert is based on a relatively simplistic averaging of radar track data and often produces false alerts. The Route Key Amendment function helps radar controllers implement route amendments, but does not help them evaluate the impact a route amendment may have on traffic conflicts, aircraft flying time, preferential routing requirements, and other factors. Traffic Management Advisor (TMA), an element of the CTAS, provides arrival sequence and scheduling advisories that help traffic managers and radar controllers maintain efficient traffic flow during arrival rushes into capacity constrained airports. TMA is currently the only radar controller tool is use today that is based on high fidelity real-time aircraft trajectory modeling.

Today, ATC control instructions must be communicated in simple messages that can be managed by the controller and pilot without automation. This would require complex 4D trajectory solutions to be broken into multiple "tactical" instructions that must be communicated to the pilot as a series of discrete maneuvers.

As congestion within the NAS grows, flow management restrictions will be needed more frequently resulting in more deviations from the user's preferred trajectories.

[This section on the OCD baseline and capabilities is extracted essentially verbatim from Reference 20]

If today's NAS was used as the baseline system, then many capabilities that can be achieved through the deployment of new DSTs and other procedures which are considered to be "enabling" technologies for CE 6, and may very possibly be deployed prior to implementing CE 6, would be incorrectly attributed to CE 6. However, if today's NAS was not used as the baseline, assumptions would need to be made as to which new DSTs and technologies would be in place before the start of CE 6 operations.

The OCD baseline is described in below, along with a summary of the capabilities attributable to the new DSTs included in the OCD baseline.

OCD Baseline: There is expected to be significant modernization of the NAS between now and the first year of implementation of Concept Element 6. In order to avoid including capabilities that can be achieved without CE 6, this OCD uses as a baseline a postulated year 2015 NAS state that includes DSTs and other modernization efforts However, some of these benefits are also obtained through the deployment of decision support tools that are under consideration and likely to be deployed prior to deployment of concept elements 5, 6, and 11the concept elements. For the purposes of our study, this means that we need to include these DSTs in our year 2015 baseline. Since OCDs have been developed for many of these DSTs and other modernization efforts, this OCD focuses on the additional capabilities provided by CE 6 above and beyond those supplied by these DSTs and efforts.

We assumed that the following DSTs are deployed NAS-wide prior to deployment of CE 6. The selection of decision support tools by name is purely for convenience and not meant to exclude any other decision support tools providing similar functionality.

- User Request Evaluation Tool (URET)
- Traffic Management Advisor (TMA)
- A conflict probe, route advisory, and trial planning DST for en route radar (R-side) controllers; e.g., Direct-To (D2)
- A DST to provide en route controllers with active, "trajectory-oriented" advisories for the metering and separation of traffic transitioning to the terminal area; e.g., En route Descent Advisor (EDA) or Problem Analysis, Resolution and Ranking (PARR).

  Such a DST is considered an enabling technology for DAG-TM en route concept elements, since it facilitates trajectory-oriented operations (as opposed to today's "sector-oriented" procedures).
- A DST to provide terminal area controllers with sequence and runway advisories; e.g., Passive Final Approach Spacing Tool (pFAST)

We also assumed that Controller-Pilot Data Link Communications (CPDLC) Build 1 and Build 1A will be implemented, as described in the FAA's OEP.

Furthermore, we expect the Reduced Vertical Separation Minimum (RVSM) program to be universally implemented in domestic airspace, all flights to file National Route Program (NRP) flight plans, and that some airports will undergo modernization (e.g., runway additions) as identified in the OEP.

Capabilities Included in the OCD Baseline: The following capabilities are assumed to be included in the OCD baseline:

Predictability

Trajectory Predictability

Decision support tools will provide improved trajectory predictability to the ATSP by providing tools capable of performing trajectory prediction. Improvements in trajectory predictability provided by CE 6 are provided beyond the following capabilities provided by the baseline:

- Trajectory orientation allows downstream effects to be considered as part of the solution to tactical problems, thereby reducing the occurrence of tactical problems.
- Decreases in separation buffers will decrease trajectory perturbations thereby improving trajectory predictability
- Decreases in missed and false alerts will result in fewer unnecessary and fewer large trajectory perturbations.

Arrival Time Predictability

Decision support tools will provide the following improvements in arrival time predictability:

- Decreases in randomly assigned delays result in an increase in arrival time predictability.
- Increases in metering fix accuracy lead to increases in arrival time predictability.

Capacity

The collection of decision support tools and procedures described above will increase capacity through a variety of mechanisms:

- Reduction in buffers used for separation and traffic flow management initiatives. This reduction in buffers is enabled through improved trajectory prediction.
- A reduction in workload for fixed traffic scenarios enables the ATSP to accept higher sector throughput.
- Improvements in flow rate conformance provide higher throughput through improved trajectory prediction capabilities.
- Higher capacity through airspace availability enabled through RVSM and NRP filing.
- Higher airport capacities at airports with capital improvements.
- Improvements in sequencing leading to higher throughput.

While similar to the capabilities provided for CE 6, the extent of the increase in capacity will be dictated by the *additional* improvements enabled by CE 6. For example, the increased availability of information by the ground DSTs provides more precise trajectory forecasts under CE 6 thereby enabling further reductions in spacing buffers.

Increased ATSP Productivity

The collection of decision support tools and procedures described above will increase ATSP productivity through a variety of workload mechanisms. The mechanisms that are considered most significant are summarized below:

- EDA notifies controllers of aircraft that are not in conformance with TFM constraints (e.g., generated by TMA) and generates advisories to comply with those constraints. In this way, EDA automates a task that is very difficult to perform accurately for long look-ahead time horizons in current operations. Similarly, EDA provides conflict resolution that is conflict-free and TFM conforming for the DST look-ahead time, reducing cognitive workload. In addition, this will reduce downstream conflicts and TFM problems, reducing the workload for downstream controllers. As an R-side capability, EDA will reduce the need to look at the URET display or be informed by the D-side controller. EDA will make managing NRP flight plans less workload intensive.
- CPDLC enables the automation of communication and control, which will significantly reduce voice communication workload. Serial voice communications can disrupt/display ongoing controller tasks. If a controller was involved in a cognitive task, the disruption may require the task to be restarted. Reducing the number of radio calls from flight deck should improve workload management. The

workload associated with radio clearances will be offset to an extent (to be determined) by workload associated with constructing data link clearances.

- RVSM will provide more usable airspace to the controller, which should reduce the workload associated with separation assurance.

Flexibility

Increased flexibility is provided to the operators by allowing more flexible flight plan filing through the NRP. While many of the DSTs allow increases in efficiency, no further increases in flexibility appear to be provided to the operators.

Efficiency

The baseline decision support tools and procedures deliver a large number of benefits in the areas of efficiency as described below:

- A reduction in buffers and a decrease in excess maneuvers decreases delays and improves fuel consumption
- Improved flight profiles are provided by RVSM and decision support tools providing improved top-of-descent placement
- Decision support tools allow higher fuel efficiency maneuvers to be selected
- Decision support tools provide a decrease in missed alerts and false alerts
- Improvements in distribution of delays to the en route airspace from the terminal area
- Higher airport throughput resulting in a decrease in delays
- Improved sequencing and runway assignments
- Improved arrival time predictability, thereby improving ground operations

3.2 Operational Policies and Constraints

The operational policies and constraints relevant to the present traffic management system are contained in References 9 and 10:

- *FAA Order 7210.3S, Facility Operation and Administration*; Part 2, Air Route Traffic Control Centers is particularly relevant to this OCD.
- *FAA Order 7110.65N, Air Traffic Control*; Chapter 2 – General Control also contains material that describes the operations of the existing air traffic control system.

3.3 Description of Current System or Situation

In the OCD baseline ATM system, remaining **trajectory prediction uncertainty** can lead to excessive deviations for separation assurance. The ATSP often compensates for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding substantial separation buffers for conflict detection and resolution (CD&R). Although such buffers enhance separation assurance, some flights experience unnecessary trajectory deviations due to the “resolution” of potential conflicts that would not have actually materialized. Even for conflicts that do exist, the buffers lead to conservative resolution maneuvers resulting in excessive trajectory deviations.

Limitations in ATSP workload negatively impact the flexibility and efficiency of user flight operations, particularly under increased levels of traffic density. Users are unable to fly their preferred trajectory unless cleared to do so by the ATSP. Poor knowledge of downstream obstacles, such as traffic congestion and traffic flow management (TFM) restrictions, places the user at a distinct disadvantage in formulating their preferred trajectory. Moreover, when trajectory deviations are necessary to conform to flow restrictions (e.g., metering), it is difficult for the ATSP to determine an efficient conformance action for that flight, let alone accommodate the user's preferred trajectory.

3.4 Users or Involved Personnel

In this section the focus is on the roles and responsibilities of each of the active participants in the present environment or situation. Users and involved personnel are identified in Table 1. Subsections address the roles and responsibilities of the ATSP, the pilot, and the airline operations center (AOC) respectively.

ATSP Roles and Responsibilities:

The controller is responsible for separation assurance (preventing, detecting, and resolving conflicts) and conformance with TFM restrictions.

The air traffic controller sends the following four types of messages to aircraft:

- Clearance. This is a required maneuver for separation, e.g., move to new altitude, new heading.
- ATC instruction. Similar to a clearance but more urgent, e.g., "go around", "turn left to (new heading)".
- Advisory. Provides a flight crew with awareness of traffic, weather, turbulence, etc.
- Traffic management directive. Informs flight crew of restricted airspace or Required Time of Arrival (RTA) assignment.

Pilot Roles and Responsibilities: The IFR aircraft pilot has responsibility for situation awareness, flight planning/replanning and execution, and adherence to clearances/instructions issued by the ATSP.

AOC Roles and Responsibilities: The AOC dispatcher has the responsibility for scheduling company aircraft and for filing flight plans and amendments that are cooperatively developed with the pilot of the aircraft in question.

3.5 Support Strategy

To be determined

Table 1. Users/Involved Personnel for Current Operations

Users or Involved Personnel	Current Operations
Traffic Management Specialist at Air Traffic Control System Command Center (ATCSCC)	
Air Traffic Control Supervisor (ATCS)	
Supervisory Traffic Management Coordinator-in-Charge (STMCIC)	
Operations Supervisors (OS)	
Traffic Management Coordinator (TMC)	
En Route Radar Position – R controller	✓
En Route Radar Associate (RA) – D controller	✓
En Route Radar Coordinator (RC)	✓
En Route Radar Flight Data (FD) Position	✓
En Route Non Radar (NR) Position	✓
Terminal Radar Position – R controller	
Terminal Radar Associate (RA) – D controller	
Terminal Radar Coordinator (RC)	
Terminal Radar Flight Data (FD) Position	
Terminal Non Radar (NR) Position	
Tower Local Controller (LC)	
Tower Ground Controller (GC)	
Tower Associate	
Tower Coordinator	
Tower Flight Data Position	
Tower Clearance Delivery Position	
Flight Service Station Specialist (FSSS)	
Airline or Aircraft Flight Operations Center (AOC)	✓
Pilot or Flight Crew (FC)	✓

4. Justification for and Nature of Change

4.1 Justification for Change

Further traffic growth will lead to increased airport and airspace congestion resulting in greater workload and delays throughout the NAS. Even with the FAA modernization under Free Flight Phases 1 and 2, traffic growth is anticipated to outpace capacity. Airspace resources are limited and further reduction in sector sizes is problematic as the overhead for coordination is reaching the point of diminishing returns.

Significant improvements to ATSP productivity will be needed to maintain separation assurance and manage congestion while accommodating the flexibility desired by users (e.g., UPTs). Dependence on the current centralized paradigm of ATSP services means that the entire infrastructure must be upgraded for any/all airspace users to improve productivity and accommodate traffic growth within a region of airspace.

A significant deficiency of the centralized approach is that its capacity to provide service is limited by ATSP resources that do not scale with traffic growth. For example, even with conflict-probe automation, a centralized ATSP is faced with the situation whereby the number of potential conflict interactions between flights grows with the square of the number of flights. Furthermore, uncertainties in trajectory prediction accuracy will require a greater frequency of tactical ATC actions to prevent/resolve problems thus increasing sector workload and deviations from the user's preferred trajectories as congestion grows.

Alternatively, a decentralized (i.e., distributed air-ground) approach to modernization may offer the potential for airspace users to contribute to the solution by equipping as needed to gain the desired level of ATSP service and productivity with increased levels of traffic.

In summary, the justification for change is that the current "centralized" approach to ATSP services has limited potential for providing significant increases in system throughput, flexibility, and efficiency with significant increases in traffic demand.

4.2 Description of Needed Changes

The following characteristics of the present system cause the user to deviate from a user-preferred path resulting in excessive or unnecessary deviations. These deviations result from: trajectory prediction uncertainty, ATSP workload limitations, and lack of user preference knowledge.

[The description of needed changes was extracted verbatim from Reference 11]

Trajectory Prediction Uncertainty: To solve anticipated air traffic conflict situations, future aircraft trajectories must be predicted. The accuracy of these predictions determines the breadth of resolution options available. If trajectory predictions are inaccurate, resolution options involving legal, but closer separation are not operationally practical. These limitations in resolution options contribute to deviations from user-preferred trajectories. Instead of a user being able to fly a user-preferred trajectory with small deviations for traffic constraints, the user may have to fly a trajectory with much larger deviations to accommodate the uncertainty of the aircraft's trajectory as well as other traffic trajectories.

Trajectory prediction uncertainty stems from several factors. Current-day ATC operations are based on a sector-oriented viewpoint, as opposed to a whole-trajectory viewpoint. This segregation of a trajectory into sector-defined portions means that trajectory adjustments that will be made in future sectors are difficult to predict (i.e., there is a lack of downstream controller intent). For the baseline situation prior to the implementation of DAG, it is assumed that ATC operations will be evolved from today's sector oriented approach to a trajectory-oriented approach facilitated by advanced en route DST automation (Reference 12).

Assuming that trajectory-oriented operations and supporting automation support adequate controller intent (a major underpinning of en route DAG operations) additional factors contribute to trajectory prediction uncertainty. Such factors include errors in estimating aircraft state, pilot intent, and atmospheric state (wind, temperature aloft), as well as uncertainty in the precision and accuracy with which a pilot responds to ATC instructions.

One effect of trajectory prediction uncertainty is the implementation of larger-than-necessary buffers for protected zones around aircraft for separation assurance. Because the future trajectory is uncertain, extra distance is added to the normal protected zones. This extra uncertainty buffer results in a separation well beyond the protected zones as illustrated in Figure 1.

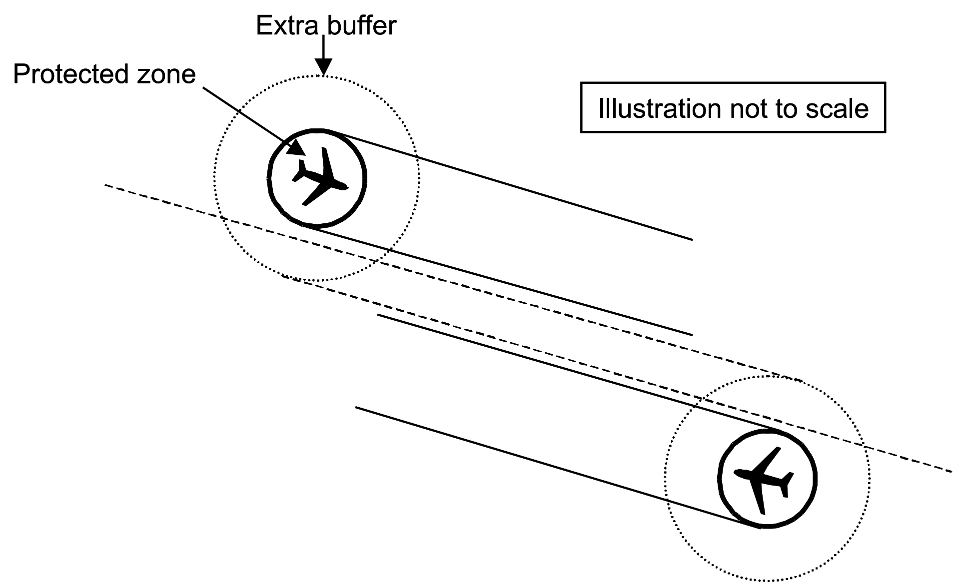


Figure 1. Aircraft Normal Protected Zones and the Effect of Larger Buffer Zones

Also, trajectory prediction uncertainty may cause excessive resolution maneuvers. Resolutions are made to avoid not only normal protected zones, but also extra uncertainty buffers. Although these solutions are robust, they also cause maneuvers that may be larger than necessary for legal separation assurance and further deviate a user from the user-preferred path.

ATSP Workload Limitations: Currently, the ATSP must provide all separation services necessary for an IFR flight's safety. These tasks include trajectory prediction, conflict detection and resolution, local traffic flow constraint conformance, trajectory adjustments, and flight plan conformance monitoring. In addition, the controller must communicate the associated instructions/clearances to flights under their control.

Controller-pilot communications are limited to ATC instructions and messages that lend themselves to verbal communications or data link transactions that can be managed manually. The lack of integration between the data link system and controller/pilot DST automation prevents data link message information from being shared with ATSP automation and FMS. As a result, precise trajectory instructions cannot be communicated in a timely manner. Even if a controller is able to use DST automation to develop conflict-free trajectory solutions, the solutions must be simplified and broken up into discrete parts that can be communicated in a tactical environment (i.e., changes in heading, altitude, and speed profile). Multiple trajectory change points must be managed by the controller sequentially in a way that allows the pilot and controller to exchange the information and execute the instruction in a timely manner. The tactical nature of this activity means that controllers must communicate several messages in a timely manner to complete a solution while the pilot is often unable to leverage the FMS to execute the controller's intended solution precisely.

The root cause of ATSP workload limitations is that the ATSP has responsibility for multiple aircraft. Therefore, the ATSP often cannot focus on any one aircraft for very long, and cannot provide individual aircraft the ability to follow user-preferred trajectories. Furthermore, as more aircraft come under the jurisdiction of the ATSP, each aircraft will have less share of the controller's attention. As traffic density increases, the ability to accommodate user-preferred trajectories decreases while the extent of TFM restrictions must be increased to prevent excessive airport/airspace congestion.

One effect of ATSP workload limitations is the imposition of larger-than-necessary buffers for protected zones. Because controllers cannot constantly monitor individual aircraft, or precisely control flight path, a buffer is added to the protected zone so that an aircraft is safe until the ATSP has time to revisit the aircraft. These buffer zones have the same effects as the zones caused by trajectory prediction uncertainty described above, and these zones are additive.

Another effect of ATSP workload limitations is a restriction of potential resolution maneuvers that require more monitoring and interaction with the user. The ATSP may select the most easily defined and implemented resolutions, because other, possibly more user-preferred resolutions would require more ATSP monitoring to implement. In the tradeoff of accommodation of user-preferred solutions versus ease of solution implementation, the ATSP must often choose ease of implementation because of workload constraints. In addition, to formulate these in-flight user-preferred resolutions would require more interactions with the user to attain the user preferences. For example, consider that each change in flight path required the controller to issue separate instructions/clearances. This increased interaction is not possible, since the ATSP also has responsibility for other aircraft.

Lack of User Preference Knowledge for Resolutions: Flight plans are filed at the beginning of a flight, and often must be changed en route because of conflict situations or adherence to local traffic flow constraints. En route adjustments to a flight's trajectory are often made without knowledge of user preferences.

The ATSP often must make trajectory adjustments without knowledge of user preferences because no tools facilitate the transfer of this information and the information is difficult to define in a way easily communicated between the flight deck and the ATSP.

The lack of user preference knowledge means that the ATSP does not take into account this knowledge when creating solutions to traffic problems. Therefore, trajectory changes due to resolution maneuvers may differ from what the user would prefer even if the user's preference would resolve the traffic problem.

4.3 Priorities Among the Changes

The top priority change introduced by DAG-TM CE 6 is the basic integration of data link with ATSP DST and FMS automation to facilitate the exchange of calibration data between air and ground automation to improve the performance of the systems. In addition, the integration of ATSP DST automation with data link is a top priority to enable DST advisories to be automatically loaded into the data link system for quick and easy communication with minimal ATSP workload.

The next priority is to integrate FMS and data link to facilitate the exchange of trajectory data. This will enable the ATSP to issue DST-generated "strategic" trajectory-based clearances that would otherwise be too complex to issue by voice and/or manually input to data link. This level of integration will also enable the pilot to negotiate UPTs with the ATSP.

In addition to the priority changes listed above, additional flight deck capabilities could be employed by the user to provide the pilot with greater situational awareness for formulating more "intelligent" trajectory preferences. For example, airborne conflict detection and resolution capabilities could be used by the pilot to modify UPT requests to avoid conflicts.

The basic change introduced by DAG-TM CE 6 is for appropriately equipped aircraft to exchange key data between air and ground automation systems. Furthermore, CE 6 enables appropriately equipped aircraft to negotiate trajectory changes with the ATSP in order to establish a new user-preferred trajectory that conforms to active local TFM constraints and avoids conflicts.

4.4 Changes Considered But Not Included

A major change that was considered, but not included, is the implementation of ATSP automation that takes responsibility for traffic separation. The so called "Automated Airspace Concept" delegates tactical separation responsibility from the human controller to ATSP automation that performs the separation assurance function and automatically data links any necessary conflict resolutions to the flight deck via data link. This conceptual approach was excluded as beyond the human-centered scope of DAG.

Another change that was considered for DAG but was not included in this concept element is that of permitting free maneuvering aircraft to identify and implement trajectory changes without prior approval from the ATSP. This change is addressed in a separate OCD for the DAG-TM CE 5 “En Route Free Maneuvering” and is described in detail in that OCD. No other solutions to this problem were considered.

4.5 Assumptions and Constraints

This section describes the assumptions behind development of the concept description for en route trajectory negotiation, conditions under which this concept applies, and the applicable operational environments. The section describes airspace structure and constraints, traffic mix and equipage, communications, navigation, and surveillance (CNS) infrastructure, and ATM environment

Airspace Structure And Constraints: CE 6 is applicable to departure, cruise and arrival phases of flight in the domestic en route operational domain, and is extensible to oceanic and terminal area domains. The airspace is sectorized within Center and TRACON jurisdictions. A route structure with named waypoints exists, but this system is not essential to the CE 6 concept. Hemispherical altitude rules and step-climb procedures exist, but these are not essential to CE 6.

Traffic Mix and Equipage: CE 6 is applicable to commercial, general aviation and military aircraft equipped to participate in trajectory negotiation. Essential avionics include accurate navigation performance, advanced FMS, and data link capabilities.

CNS Infrastructure: Data link communication integrates ATSP, FD and AOC operations. Air-ground data link provides two-way communication between the FD and the ATSP and between the FD and the AOC. Addressable and broadcast air-ground communications are employed as appropriate. Ground-ground data link provides two-way communication between the ATSP and the AOC. Air-ground voice communications continue to be used, but are replaced to the extent appropriate by data link.

The Global Positioning System (GPS) is certified for en route navigation, but not necessarily as sole means. Advanced FMS units support data link-based trajectory negotiation transactions between the ATSP and FD.

FMS-derived aircraft state and intent data is downlinked to the ATSP and fused with secondary surveillance radar (SSR) data to provide accurate trajectory and situation assessment information.

ATM Environment: The controller is supported by DST automation for conflict probe and TFM conformance to facilitate trajectory-oriented operations. To support CE 6 operations, ATSP DST automation is integrated with data link to facilitate the communication of key data, ATC instructions, and trajectories between the ATSP and user.

5. Concept for a New or Modified System

5.1 Background, Objectives, and Scope

[The following background is extracted verbatim from Reference 2]

Background: DAG-TM is a human-centered operational concept for minimizing the impact of ATM constraints by leveraging new procedures and technological innovations in automation aids, information sharing, and supporting technologies. In the DAG-TM concept, flight crews, air traffic service providers (controllers and traffic managers), and airline operational control personnel (flight planners/dispatchers) utilize distributed decision-making to maximize user flexibility and system throughput. While near-term NAS-modernization efforts focus on the evolutionary enhancement of ATM systems, DAG-TM focuses on the longer-term procedural and technical integration of airborne, flight planning, and ATM systems to facilitate more decentralized and dynamic management of the NAS. The goal of DAG-TM research is to determine a possible end state towards which current systems should evolve. Once the operational considerations for DAG-TM are understood for the U.S. NAS, global interoperability of aircraft systems can then be facilitated via international collaboration to establish common baselines for aircraft systems and avionics, and interoperability requirements for ground systems.

The DAG-TM concept was formulated to enhance the industry's operational concept for Free Flight in 2005 and beyond (Reference 13). DAG-TM proposes a concept of operations for the 2015 time frame, and defines in greater depth the more "aggressive" Free Flight applications outlined by the RTCA Task Force 3 report (Reference 3). Where appropriate, the DAG-TM team leveraged or enhanced applicable concepts from previous NASA and industry efforts such as the FANG (FMS-ATM Next Generation) project (Reference 14). The purpose for formulating the DAG-TM concept was to organize and focus NASA research activities to develop and validate key Free Flight concepts.

DAG-TM is a gate-to-gate operations concept that spans all phases of flight within the NAS, with consideration for the operational needs of a diverse airspace user community (airline, general aviation, and military). Mixed aircraft equipage (capability) is assumed to be the norm, not the exception, with various classes of airspace accessible to most, if not all, user classes. It is desirable to minimize mandated equipage levels for access to airspace. This would allow greater flexibility in capital-investment decisions for all user classes, and differs from some of the related "free-routing" concepts under consideration in Europe (Reference 15).

Objectives: The objectives of DAG-TM CE 6 are to integrate ATSP and user automation with data link to:

- Reduce unnecessary and/or excessive ATSP-issued route deviations for traffic separation by enhancing ATSP trajectory prediction capability through user-supplied data on key flight parameters.
- Reduce ATSP workload (and increase throughput) by reducing controller task loading associated with separation assurance and conformance to TFM constraints.

- Facilitate trajectory change requests for en route aircraft by providing the user (the FD and/or AOC) the capability to formulate a conflict-free user-preferred trajectory that conforms to any active local-TFM constraints.

<u>Scope:</u> The scope of DAG-TM CE 6 (same as CE-5) is limited to en route airspace operations only with a focus on trajectory-related decisions for individual flights related to user-preferred flight-path optimization, separation assurance and obstacle avoidance, and conformance with flow restrictions as defined by the ATSP.

While the ATSP retains full responsibility for separation assurance (i.e., flight-path changes require ATSP approval), the users are integrated into the solution processes. By comparison, CE-5 distributes responsibility for separation assurance to allow equipped aircraft to maneuver freely.

DAG CE-7/8 provide for the TFM complements to CE-5/6, namely collaboration to determine user-preferred TFM flow restrictions for which users must conform to under CE-5/6 operations.

It is emphasized that the ATSP retains full responsibility for separation assurance.

5.2 Operational Policies and Constraints

The operational policies and constraints relevant to the present traffic management system are contained in References 9 and 10:

- *FAA Order 7210.3S, Facility Operation and Administration*; Part 2, Air Route Traffic Control Centers is particularly relevant to this OCD.
- *FAA Order 7110.65N, Air Traffic Control*; Chapter 2 – General Control also contains material that describes the operations of the existing air traffic control system.

Modifications to current policies and constraints relevant to en route and terminal air traffic management will have to be modified in accordance to the final CE 6 requirements. Details will be defined when CE 6 reaches higher Technical Readiness Levels (TRLs).

5.3 Description of the New or Modified System

5.3.1 Trajectory Negotiation (DAG CE-6) Overview

It is assumed that the ATSP is equipped with advanced DST automation at the sector level to support “trajectory oriented” (ATC) operations as described in the OCD Baseline. For DAG CE-6, the ATSP DST automation is integrated with data link and FMS to enable mechanisms for:

- Exchanging data to improve the performance of DST automation;
- Reducing the ATSP workload associated with the communication, monitoring, and execution of 4D trajectory solutions for separation assurance and TFM conformance; and
- Dynamically incorporating user preferences into ATSP assessment and resolution (or avoidance) of potential ATC problems.

The user (the FD and/or AOC) will provide information via data link on key parameters such as aircraft weight, trajectory intent (route, altitude, speed profile), local winds/temperature aloft, and navigational performance (References 16 and 17). The provision of this information will not adversely affect FD and/or AOC workload, and will be automated. An ATSP-based decision support tool (DST) will use this data to improve its trajectory predictions, resulting in improved Conflict Detection and Resolution (CD&R) performance. This improvement will: (1) reduce the number of unnecessary conflict resolution maneuvers by decreasing the conflict prediction false-alarm rate; and (2) reduce the extent of excessive trajectory deviations for conflict resolution by decreasing the uncertainty in future positions of the aircraft.

The integration of ATSP DST automation with CPDLC will enable ATC instructions (DST advisories) to be automatically loaded for up link to the FD. The integrated system also enables the ATSP DST automation to automatically read down link messages from the FD. This integration reduces the controller's task loading for generating CPDLC messages and maintaining the automation's model of intent. Appropriately equipped users with CPDLC capability integrated with their FMS will enable controllers to issue more strategic trajectory-based instructions that can be precisely flown by FMS and require fewer ATC instructions to be communicated.

Appropriately equipped users will be able to submit their preferences for meeting TFM constraints (e.g., RTA). By making use of information on local traffic and TFM constraints, the user is able to formulate intelligent trajectory change requests that are likely to be acceptable to the ATSP and therefore less workload-intensive for the ATSP to evaluate and coordinate. Using data link, the AOC transmits relevant information on airline preferences/constraints to the FD. The flight crew uses a FD-based trajectory planning decision support tool to compute a user-preferred trajectory that conforms to any active local TFM constraints (bad weather, Special Use Airspace (SUA), airspace congestion, arrival metering/spacing). If optionally equipped to do so, the user could leverage Cockpit Displays of Traffic Information (CDTI) and Airborne Separation Assurance Systems (ASAS) to formulate conflict-free trajectories. The FD transmits the desired trajectory to the ATSP via data link. These preferences may include (but are not limited to): a specified 4D trajectory; a specified route, and/or altitude and/or speed profile; or, preferred degree(s)-of-freedom (route, altitude, speed) for conflict resolution.

The trajectory negotiation process may involve single-flight collaboration between the ATSP and an individual user, or multiple-flight collaborations between the ATSP and multiple users for determining a balanced set of deviations among a "gaggle" (group) of flights. The ATSP uses their DST to review the request, and in most cases, finds the request acceptable and issues a clearance for the new trajectory. If the request is not acceptable, the ATSP denies the request and may use their decision support tool to formulate an alternative clearance or provide additional information on ATSP requirements/constraints.

Following the selection of a conflict-resolution plan, the ATSP then transmits (via data link) the conflict-free trajectory solutions to the appropriately-equipped aircraft for execution (thereby further reducing trajectory uncertainty and subsequent conflict false-alarm and missed-detection rates).

5.3.2 Air-Ground Integration

For effective trajectory negotiation, CE 6 requires the **operational** and **technical integration** advanced ATSP, FD and AOC automation using advanced communications capabilities and human-centered pilot and controller pilot procedures and technologies. These functions must be properly structured and integrated to enable users and the ATSP to evaluate traffic situations accurately and determine and implement courses of action that are timely, effective, and efficient. The operational integration focuses on the establishment of human-centered processes and interfaces for using the computer-derived information cooperatively among the ATSP, FD and AOC to make the best use of trajectory negotiation. The technical integration focuses on derivation, transmission and compilation of valid flight data for use by computerized systems to evaluate and predict actual trajectories, identify and examine constraints and generate trajectory alternatives with high accuracy.

Operational Integration: CE 6 implements trajectory negotiation by providing the ATSP and users with the means for exchanging key information to improve situation assessment, and trajectory planning, and trajectory execution. This key information includes trajectory data and TFM constraints that would be too complex to communicate by voice or manually exchange through data link. Such integration enables ATSP to better predict, evaluate, and accurately control trajectories with consideration for user preferences (as defined by the AOC and/or flight crew):

- The AOC provides user flight operations and aircraft performance descriptors to the ATSP and the FD provides updates of trajectory status, intent, preference and atmospheric measurements to the ATSP. This information is integrated into the ATSP surveillance, flight data and associated computational processes to enhance decision support tool performance.
- The ATSP provides the users with atmospheric forecasts and local TFM constraints such as RTA, altitude, speed or spacing restrictions, route restrictions due to special use airspace, weather or sector traffic congestion, and airport acceptance rates and delays.
- The ATSP provides users with information describing potential violations of aircraft separation and TFM constraints, and may provide information describing ATSP-generated trajectory resolution alternatives or restrictions applicable to user-generated resolutions.
- The ATSP uses data link to communicate trajectory-based clearance instructions. This enables the ATSP to leverage DST capabilities to generate 4D trajectory solutions (for separation assurance and metering) that can be communicated to the flight deck and precisely executed by FMS-equipped aircraft.

These data exchange and trajectory evaluation exercises enable the ATSP and users to determine and negotiate clearances that provide efficient resolutions of potential violations of aircraft separation and TFM constraints or permit efficient trajectory changes in response to user requests.

The CE 6 operation employs a human-centered operational design that leverages the advanced capabilities of the automation, pilot and controller computer-human interface (CHI), and CNS functions available in the DAG-TM environment. A key component of these functions is improved trajectory prediction and assessment, which enables extended probing along the projected trajectory to perform aircraft CD&R and TFM constraint infraction detection and resolution. A theoretically perfect CE 6 trajectory prediction and assessment function would support resolution of all potential violations along the entire trajectory prior to each aircraft's entry into en route airspace. The theoretical limit of en route probing would be the implementation of user and ATSP-negotiated, violation-free 4D flight plans, which would eliminate potential conflicts while satisfying any local TFM constraints. Delays and diversions from the negotiated flight plan would be precluded in this theoretically perfect operation.

In the realistic environment of CE 6, trajectory prediction and assessment is not perfect and its accuracy diminishes with longer look-ahead. However, trajectory analysis in the DAG-TM environment would be superior to that of current operations, and CE 6 trajectory accuracy would support reliable aircraft CD&R and local TFM constraint probing well beyond the scope defined by current sector sizing practices. Hence, CE 6 implements trajectory negotiation for airspace that currently would be a multi-sector environment such that the ATSP evaluates aircraft separation and local TFM requirements over an extended downstream look-ahead span. Trajectory negotiation is used to establish a reliable violation-free plan for the effective range of the aircraft CD&R and TFM constraint probe. Notionally, the ATSP monitors the flight along a previously negotiated trajectory and would not intervene except when or until a violation is projected.

ATSP automation operates a potential conflict and TFM constraint probe along a projected trajectory. This trajectory may be that corresponding to the currently predicted flight path, a user requested change, or an alternative flight path. The probe generates alerts of potential violations. The probe's look-ahead range is based on concerns of preventing missed alerts and limiting false alarms, and is determined by the accuracy of the trajectory prediction model. The probes application should avert the worst case scenario depicted in Figure 2 in which the resolution of false alarm leads to a missed alert.

CE 6 uses the probe in an algorithmic process that generates mutual resolution of aircraft separation and TFM constraints. Based on previous research (Reference 12) the process is one that first resolves the TFM constraints and then uses this solution as a boundary condition for the potential conflict solutions. This inner-outer loop calculation approach is effective when flow-rate conformance accuracy is small compared to the separation requirement. Accuracy of this magnitude is required for CE 6 trajectory prediction and the corollary capability to deliver aircraft to a fix according to plan.

ATSP automation compiles and distributes TFM constraints, meteorological and traffic data to users by data link to enable users to generate acceptable trajectory change requests in the CE 6 concept. Data describing airspace and airport congestion, meteorological forecast, severe weather, SUA, and flow rate constraints is voluminous, and would be used by AOC automation to determine flight plan and schedule preferences and constraints. These data are transmitted to the aircraft for use in aligning specific trajectory change requests with dynamic local TFM constraints, subject to potential conflict resolution.

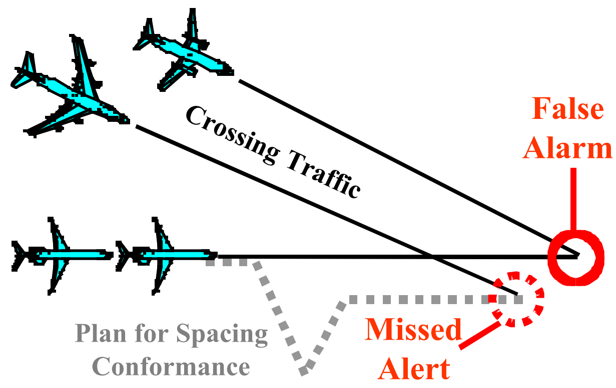


Figure 2. Avoidable Interruptions

Local TFM constraint and meteorological data transmitted to FD by the ATSP would need to be compatible with FMS processing capabilities. These data are succinct specifications of metering and procedural restrictions and wind and temperature forecasts along the predicted trajectory. Figure 3 illustrates an example of an FMS determining a preferred descent profile in response to an altitude restriction, enabling negotiation of the top of descent location.

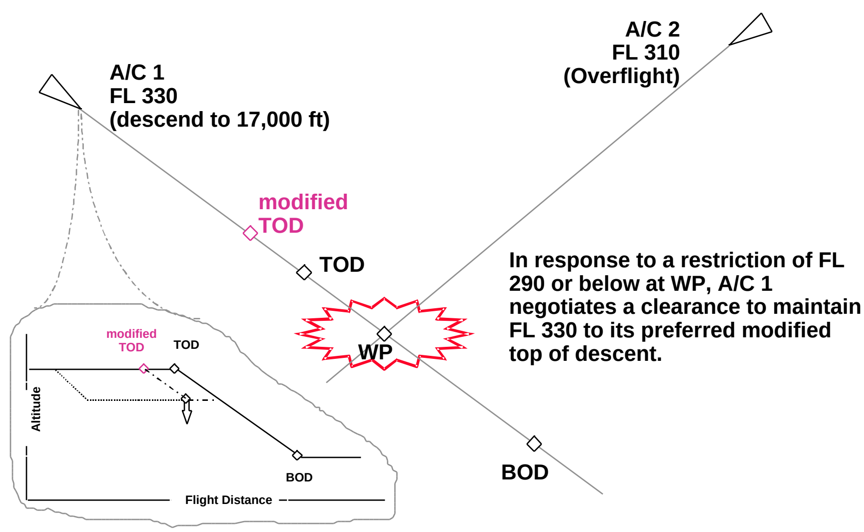


Figure 3. Application of an Uplinked Waypoint Constraint

To further support FMS assessment of potential trajectory changes, the ATSP also may provide TFM constraints and meteorological data for reference points along logical alternative trajectories. In all likelihood, RTAs or RTA ranges would be required rather than miles-in-trial spacing unless the FD is capable of processing and integrating trajectory data for other traffic into the TFM constraint information to determine spacing fit. These data requirements further accentuate the need for accurate and efficient trajectory modeling by ATSP automation.

This control-by-exception operation is based on a trajectory-centric, rather than sector-centric, concept for distributing separation assurance responsibility. Theoretically, a trajectory-orientated ATSP operation might be established without sectorization in a futuristic environment. However, for planning purposes based on practical considerations, CE 6 is assumed to operate in a sector structure similar to that currently employed. In this operation, the probe examines aircraft separation and local TFM constraints in the multi-sector airspace that includes the current and downstream sectors. Negotiation is used to agree on a violation-free trajectory plan for this extended range, alleviating requirements for subsequent downstream intervention.

The CE 6 controller and pilot operating procedures and associated CHI are designed to support the following: automation-assisted uplink of ATSP trajectory-based instructions, dissemination of constraint information for trajectory planning and management, and trajectory negotiation. ATSP data entry and display, decision support tool and communication systems are integrated to reduce the workload associated with the detection and resolution of ATSP problems (separation assurance and TFM conformance). The CHI allows for the handling of a range of complex potential violation or constraint conformance situations. The aircraft involved in a potential violation may be in the same sector as each other at the time of negotiation or in different sectors, and the location of the potential violation may be the sector containing one or more of the subject aircraft or a downstream sector. Trajectory constraint specifications may pertain to a single reference fix and control parameter, or a sequence of fixes and combinations of parameters defining crossing time, spacing, speed, altitude or other traffic management requirements.

Controllers are provided with capabilities to define a trajectory solution or solution options, and to test, evaluate, bound, accept, adjust or reject trajectory options generated by ATSP automation tools and user-generated trajectory change requests. Pilots are provided with capabilities to assess, bound, accept, or reject FD or AOC-generated trajectory change requests and ATSP-generated trajectory resolutions. Pilots are able to accurately execute precise ATSP-generated trajectory resolutions and reduce ATSP workload associated with conformance monitoring. Dispatchers have analogous capabilities. Controllers, pilots, and dispatchers are able to respond to each other's trajectory plans as part on the process of achieving consensus.

Technical Integration: The CE 6 operation is enabled by advanced ATSP, FD and AOC automation coupled with advanced CNS technology. These technologies provide the mechanisms for reliably determining and describing the attributes, state and intent of aircraft and the air traffic system, accurately evaluating aircraft separation and TFM constraint factors, correctly determining trajectory options and preferences, and effectively performing trajectory negotiation. A critical technical integration component is an air-ground and ground-ground data link system that enables the efficient exchange of data among the ATSP, FD and AOC.

Automation tools are used in CE 6 to assist controllers with separation assurance and conformance to local TFM constraints. These automation tools provide the controller with advisories based on trajectory prediction and assessment calculations using highly-accurate information describing aircraft operating characteristics, traffic, TFM constraints, and atmospheric conditions. Flight deck automation assists the pilots with the precise trajectory planning and execution according to pilot, AOC, and ATSP constraints. AOC automation assists the dispatcher in the planning/re-planning of user-preferred trajectories (that are communicated to the pilot) to meet the fleet and/or mission needs of the user.

Integration of ATSP and user automation with data link enables the automatic exchange of calibration data describing aircraft and system attributes, and facilitates exchange of trajectory negotiation data between the ATSP and users. The integration of the DST automation with data link enables the DST automation to receive, analyze, and transmit precise trajectory-based data that would be too complex to communicate by voice or input into the automation manually.

Calibration information is transmitted between the ATSP and user computer operations using automated data link capabilities. These messages contain information used by ATSP, FD and AOC automation to perform high-fidelity modeling of trajectories, traffic situations and atmospheric conditions. Calibration data describe flight operations and aircraft performance factors, aircraft state and trajectory intent, and atmospheric measurements and forecasts. Calibration data improves the accuracy of ATSP and user automation.

Trajectory-based transactions between controllers, pilots or dispatchers include trajectory preference and preference interrogation, trajectory change request, trajectory constraint, trajectory clearance, and acceptance and rejection messages.

Flight deck avionics systems are integrated into the CE 6 operation. Aircraft FMSs process calibration and negotiation data. FMS units generate aircraft status, trajectory intent and atmospheric measurement information for air-ground down linking. FMSs also generate trajectory preference and restriction data, and provide pilot interface capabilities for conducting trajectory negotiation with the ATSP. The accuracy of the status and intent data and the capability to maintain trajectory clearance conformance depend on the performance levels of the navigation and guidance systems onboard aircraft.

AOCs generate flight plan and operations data that are used in ATSP and FMS trajectory prediction and assessment computations. AOC decision support tools provide dispatcher interface capabilities for conducting trajectory negotiation with the ATSP by ground-ground data link and with pilots by air-ground data link.

CE 6 Technical Architecture: Figure 4 is a high level diagram of the CE 6 Technical Architecture showing those NAS systems and services that are essential for supporting CE 6. Current and future air traffic systems and services that are general to ATM but not specifically utilized in CE 6 are not shown.

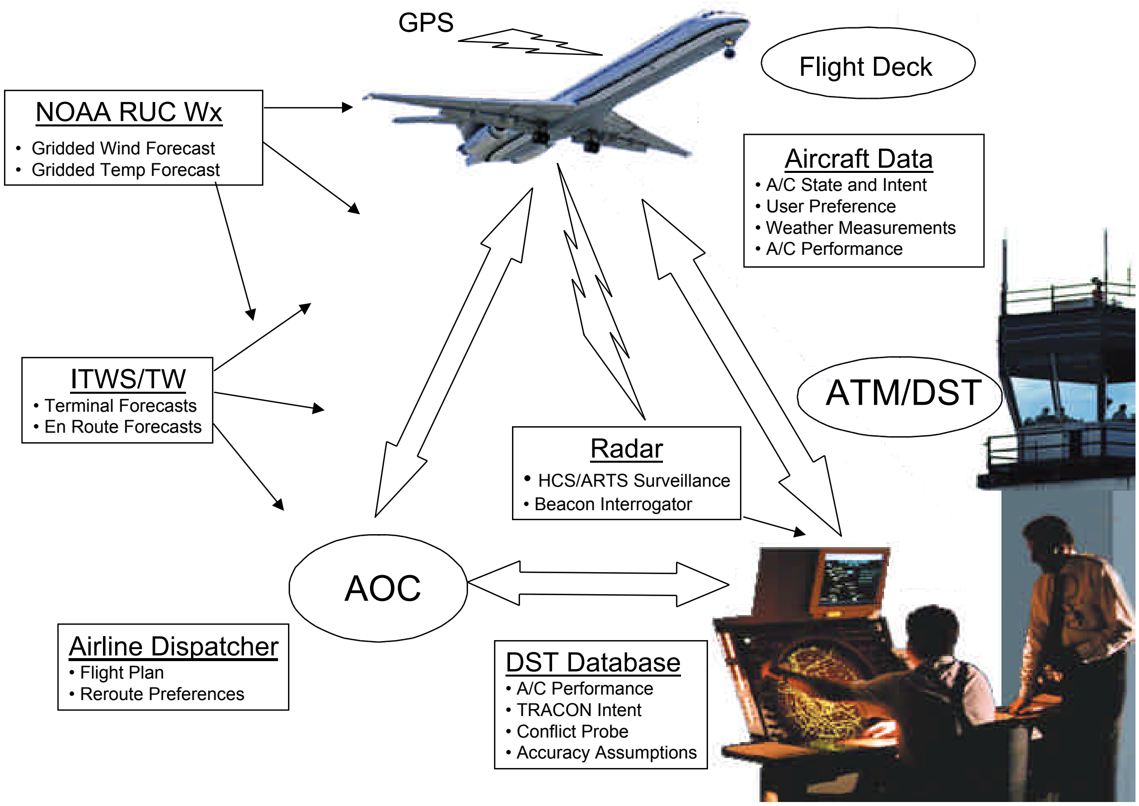


Figure 4. CE 6 Technical Architecture

5.4 Users/Affected Personnel

This section addresses impacts on CE 6 on the roles and responsibilities of the active participants, focusing on controller and pilots. Table 2 however presents a summary of all affected personnel. This table is the same as the Table 1 (Current Operations); however, the roles and responsibilities of each involved personnel is changed somewhat under CE 6.

Table 2. Users/Involved Personnel for CE 6 Operations

Users or Involved Personnel	CE 6 Operations
Traffic Management Specialist at Air Traffic Control System Command Center (ATCSCC)	
Air Traffic Control Supervisor (ATCS)	
Supervisory Traffic Management Coordinator-in-Charge (STMCIC)	
Operations Supervisors (OS)	
Traffic Management Coordinator (TMC)	
En Route Radar Position – R controller	✓
En Route Radar Associate (RA) – D controller	✓
En Route Radar Coordinator (RC)	✓
En Route Radar Flight Data (FD) Position	✓
En Route Non Radar (NR) Position	✓
Terminal Radar Position – R controller	
Terminal Radar Associate (RA) – D controller	
Terminal Radar Coordinator (RC)	
Terminal Radar Flight Data (FD) Position	
Terminal Non Radar (NR) Position	

Tower Local Controller (LC)	
Tower Ground Controller (GC)	
Tower Associate	
Tower Coordinator	
Tower Flight Data Position	
Tower Clearance Delivery Position	
Flight Service Station Specialist (FSSS)	
Airline or Aircraft Flight Operations Center (AOC)	✓
Pilot or Flight Crew (FC)	✓

An overview of CE 6 operational sequences is shown in Figure 5.

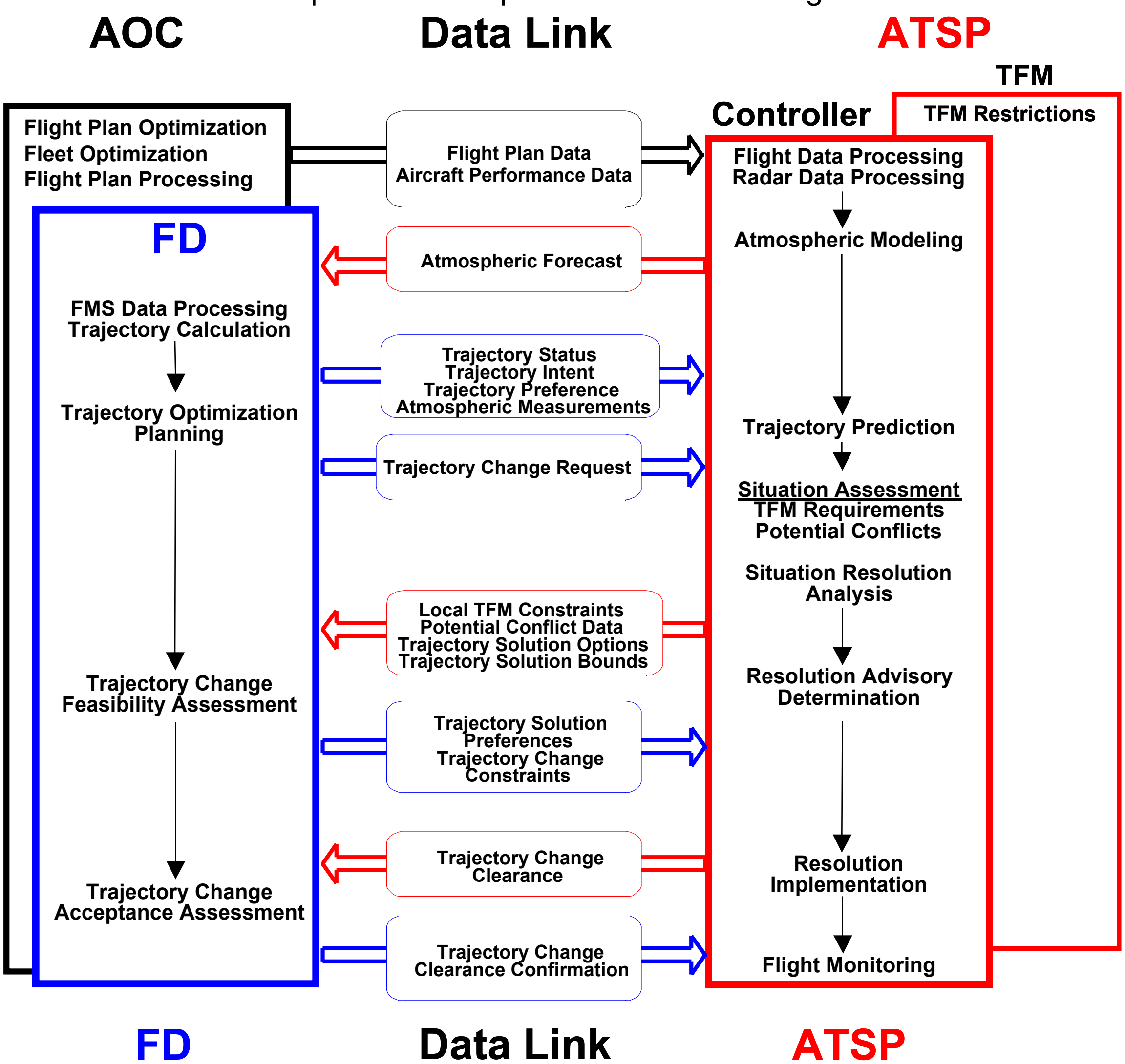


Figure 5. CE 6 Operational Sequence Overview

<u>**ATSP Roles, Responsibilities, and Operations:**</u> The air traffic controllers manage aircraft in a similar manner as today, still retaining responsibility for maintaining separation assurance. However, controllers employ advanced decision support tools integrated with data link communication to facilitate the planning, negotiation, and

execution of precise 4D trajectory solutions that enable UPTs while resolving conflicts and conforming to TFM restrictions.

It is assumed that the ATSP is equipped with advanced DST automation at the sector level to support “trajectory oriented” (ATC) operations as described in the OCD Baseline rather than being predominantly focused on airspace internal to their individual sectors. Sector teams work cooperatively to develop trajectories clearances that conform to aircraft separation and TFM constraints in multi-sector airspace so that downstream sector teams subsequently have less need to perform trajectory intervention.

CE 6 ATSP automation provides controller interfaces for managing the trajectory prediction, probing and conformance resolution operations and conducting trajectory negotiation with FD.

Data entry and display devices and attendant procedures provide controllers with options to select aircraft streams and reference fix subjects for traffic flow management. Aircraft streams are defined according to flight origin or destination, routing, flight direction, airspace region to be penetrated, aircraft type, or other logical classification. A reference fix may by an individual published waypoint or a temporary waypoint manually positioned by controllers, a set of waypoints, and arbitrary arc, a formal boundary, or other meaningful designator. Reference fixes may be in the controller’s sector airspace or downstream sectors.

Generally, a network of reference fixes would be established to manage multi-sector traffic. Controllers in different sectors would use this common set of reference fixes to coordinate operations. By this process, sector teams would determine aircraft separation and TFM constraint conformance resolutions based on common traffic planning goals (e. g., crossing time schedules or spacing restrictions at waypoints several sectors downstream).

Controller’s have options for managing the resolution tactics applicable to aircraft separation and TFM constraint violations and trajectory change requests. Controllers define the degree of freedom permissible for use by decision support tools in constructing trajectory options. These allow trajectory changes to be defined according to speed, altitude, vectoring and routing parameters or to be unconstrained. Controllers use decision support tools to plan trajectory solutions for resolving conflicts and potential conformance violations.

ATSP trajectory negotiation with the FD is conducted using an extensive set of formalized data link messages supported by data display and entry devices that facilitate message manipulation. The messages are structured parametrically to enable efficient transmittal of trajectory intent, preference, constraint and request data and approval, rejection and acknowledgement information. The message data composition and format are such that they are readily understood and processed by controllers, pilots and automated functions.

Pilot Roles, Responsibilities, and Operations: In CE 6, pilots remain responsible for conforming to controller instructions. Depending on equipage, pilots accept responsibility for conforming to more complex instructions (communicated by data link) that leverage their aircraft’s capabilities.

Pilots use the FMS interactive display function integrated with data link communication to conduct trajectory negotiation with the ATSP. CE 6 provides pilots with concise trajectory negotiation procedures and capabilities to modify trajectory planning parameters and modify, exchange, store and retrieve active and provisional trajectories in the FMS.

Appropriately equipped aircraft may also receive trajectory-based ATC clearances and instructions that are more complex than those that are operationally acceptable today. Such instructions will require automation assistance (e.g., appropriate FMS) to review, accept, and execute accurately in a timely manner. These more “strategic” trajectory-based instructions may involve multiple trajectory/profile change points and/or RTA. In the case of an RTA instruction, the controller delegates to the pilot (upon pilot acceptance) responsibility for conforming to that RTA (the precision of RTA conformance will need to be defined through operational studies).

FD operations in CE 6 are complimentary to those described in the preceding paragraphs for the ATSP. FD exchanges trajectory data with the ATSP, determines trajectory preferences, and negotiates clearances. The FD would not have computerized computational resources comparable in processing capability to those of ATSP automation, and FD operations are scaled accordingly. Flight-specific and time-responsive trajectory analysis tools and concise negotiation procedures are essential to FD participation in CE 6. Precise trajectory-based clearances would be problematic if managed manually.

Pilots view and compose data link messages using selectable menus. Trajectories transmitted to FD for negotiation define an extended 4D flight path or near-term maneuver requirements. The extended 4D flight path describes crossing time, speed and altitude for waypoints along the projected trajectory. Near-term maneuver requirements describe speed, heading or altitude assignments or bounds on these assignments. The FMS automatically reviews the message to confirm consistency with aircraft performance capabilities, and advises the pilot accordingly on the message display. Inconsistencies between ATSP and FMS aircraft models, databases and trajectory analysis algorithms, such as those involving dissimilar speed, altitude or route change or heading/vectoring/path stretching solution strategies, would disrupt the negotiation process and are precluded in CE 6 through standards and data exchange.

Pilots also perform a logical validation of the ATSP trajectory proposal. At minimum, pilots have the option to respond to an uplinked message with and affirmative acknowledgement (i.e., ROGER), affirmative acknowledgement with automated loading of the message into the FMS mode control selection panel (i.e., ROGER/ENTER), or negative acknowledgement (i.e., UNABLE). Pilots may also choose to examine trajectory options to determine preferences. Previous research (Reference 19) indicates that negotiation procedures should be established that would enable the FMS to automatically generate a trajectory preference or trajectory change request based on pilot-set parameters. For example, the pilot would specify the speed range usable by the FMS in determining a profile, or accept or modify speed bounds suggested by the ATSP. The pilot would review the resulting profile to assess acceptability.

AOC Roles, Responsibilities, and Operations: AOC/dispatch responsibilities remain the same as today.

AOC decision support systems would take advantage of the wind and weather forecasts, consistent with the ATSP, to update flight planning and flight following factors, and make timely determinations of requirements to update the filed flight data. The ATSP-disseminated atmospheric parameters would locally calibrate a common ATSP and AOC gridded weather database, reducing instances of inconsistent trajectory assessments between ATM and AOC systems. AOC transmits aircraft performance and flight operations information to the ATSP and trajectory planning information to the aircraft. The AOC transmits trajectory preference updates to FD by data link as warranted by flight plan analysis.

5.5 Support Strategy

To be determined

6. Operational Scenarios

This section discusses and illustrates the modes in which the CE 6 concept has to operate in order to be successful.

Figure 6 provides a perspective on the CE 6's fit into broader TFM operations. The figure illustrates a case in which aircraft bound to Chicago O'Hare International Airport (ORD) are subject to delay due to airport capacity overload. The delay is systematically propagated upstream through a series of organized flow constraints which result in dynamic local TFM constraints on ORD-bound aircraft exiting Denver Center (ZDV). The constraints may be miles-in-trail spacing-based or time-based metering requirements. TFM constraints may include altitude, speed and other procedural restrictions. The constraints are applicable at specific reference fixes or jointly applicable at the Denver Center's outbound boundary regardless of crossing point and altitude. These local TFM constraints are further propagated within Denver Center as metering and procedural restrictions applicable at individual sector boundaries are or within sectors.

The ORD-bound flights depicted in Figure 6 generally are in cruise or climb mode in Denver or Minneapolis Center airspace, and negotiations focus on completing climb profiles if appropriate and defining and establishing downstream cruise trajectories. But, as these aircraft approach ORD, such as when flying through Chicago Center airspace, the CE 6 operation also considers descent requirements pertinent to terminal area traffic operations in examining downstream aircraft separation and TFM constraints. These trajectory negotiation processes require integration with arrival and departure sequencing and spacing automation.

Each sector team responsible for TFM constraint conformance conducts trajectory negotiation with aircraft in its airspace. The constraints are applicable at reference points within the sector or at downstream points. Trajectory negotiation for downstream constraint conformance takes into account traffic factors along the multi-sector trajectory including the resolution of conflicts along the path (i.e., trajectory-oriented ATSP operations).

Potential violations of aircraft separation requirements exist concurrently with local TFM constraints or in isolation if flow management is not in effect. In either case, the locations of potential conflicts in multi-sector airspace addressed by CE 6 are analogous to those illustrated in Figure 7. The CE 6 multi-sector scope is not restricted to adjacent sectors as shown in Figure 7, but this four-sector configuration illustrates potential conflict-airspace combinations relevant to trajectory negotiation. These potential conflicts in general include aircraft crossing, merging and overtaking situations for climb, cruise and descent modes.

The intrasector and external potential conflicts (Cases A and B in Figure 7) are situations in which each aircraft conduct trajectory negotiation with the same sector team. The ATSP negotiation process in the intrasector situation (Case A) is within the jurisdiction of that sector team. But in the external situation (Case B) where the potential conflict point is in a downstream sector, the upstream sector is responsible for addressing downstream separation assurance in the negotiation process.

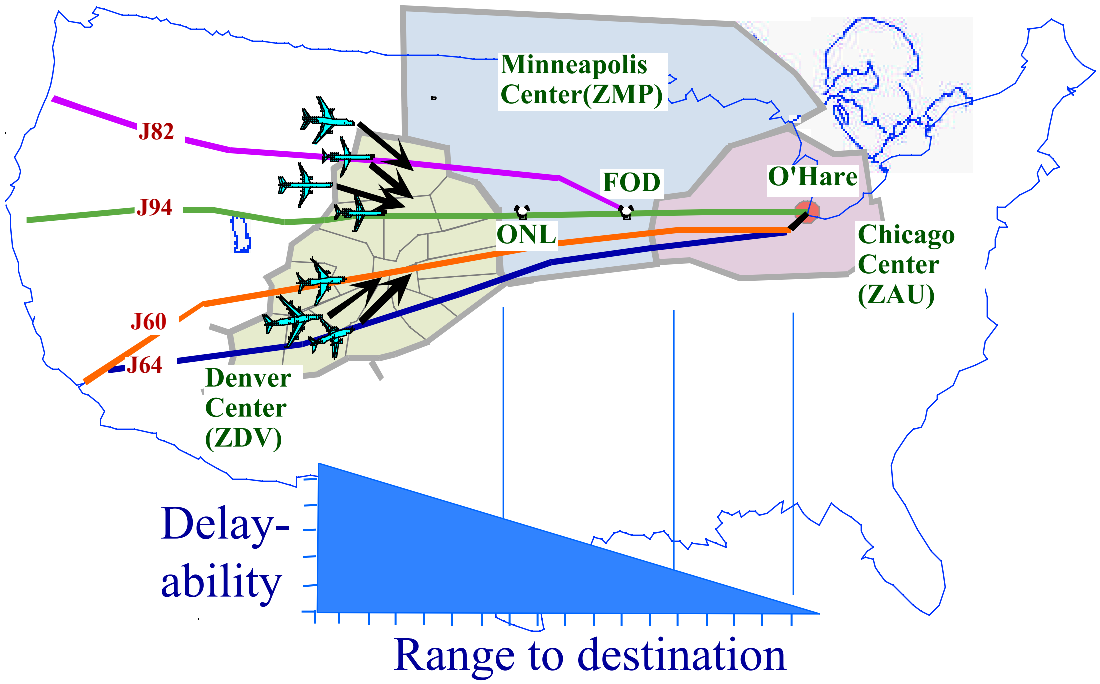


Figure 6. En Route TFM Constraint Propagation

The external intruder and intersector potential conflicts (Cases B and C) are situations in which each aircraft conduct trajectory negotiation with sector teams that do not own the airspace within which the conflict (or TFM restriction) resides. Any negotiation of trajectory solutions involving such conflicts are conducted in accordance with the jurisdictional responsibilities of both sector teams.

Trajectory negotiation also is invoked in response to a user request to change the trajectory, normally based on flight plan optimization. The request generates an ATSP examination of the requested trajectory for TFM constraints such as those depicted in Figure 6 and potential conflicts such as those depicted in Figure 7. The negotiation is conducted between the aircraft and its current controlling sector team, and could involve consideration of downstream sector jurisdictional responsibilities.

The remainder of this section divides the discussion into three sub-sections addressing normal or nominal modes, rare-nominal modes, and failure modes.

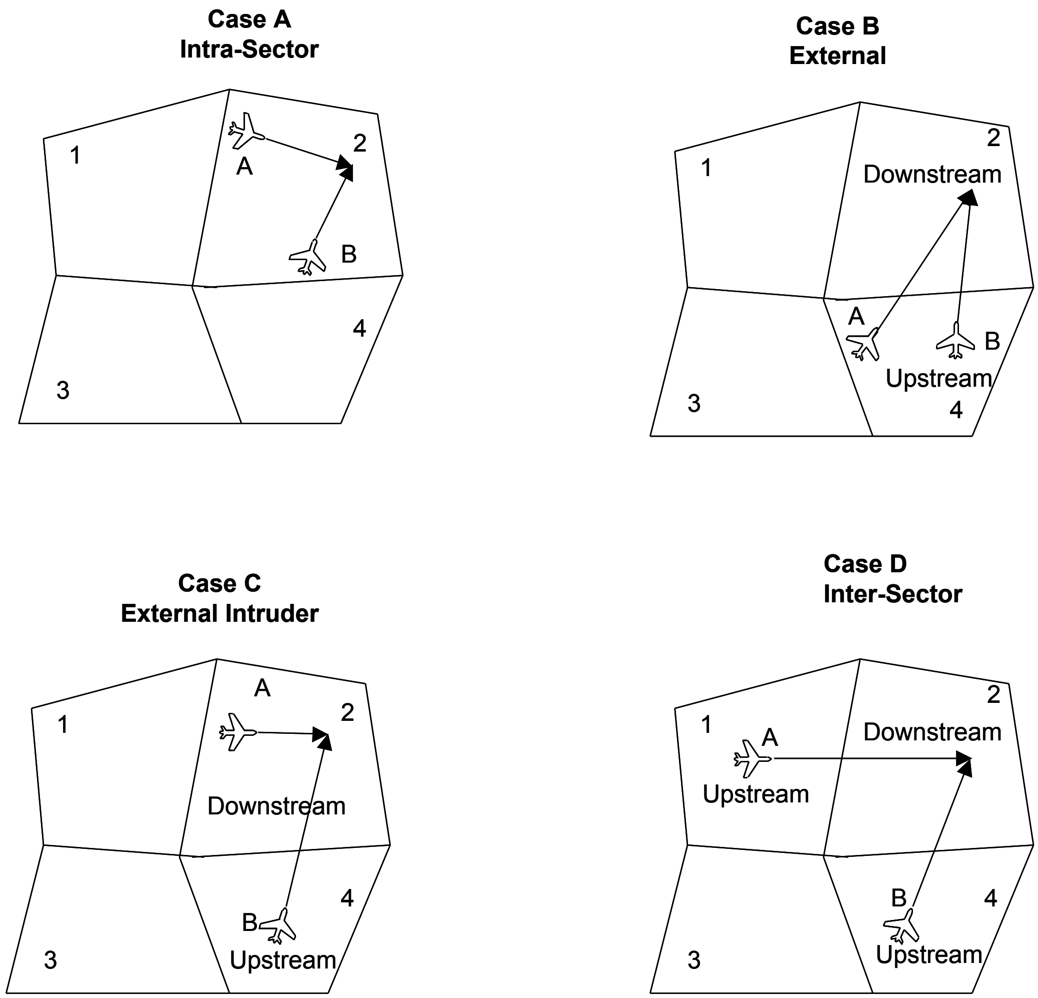
Normal or Nominal Mode: The discussion of the nominal operating modes of CE 6 will include the three operational enhancement mechanisms facilitated by CE 6:

- Basic data exchange;
- Integration of controller DST with data link; and
- Integration of controller DST with FMS via data link.

Basic Data Exchange

Before the departure of BRC926, a LAX to ORD flight, the AOC submits information to the ATSP describing trajectory intentions and preferences specific to today's flight and the aircraft's standard performance characteristics. These calibration data include takeoff weight, runway preferences, acceptable delay factors, climb, descent and cruise profile characteristics, and the aircraft engine and aircraft operating specifications.

Figure 7. Multi-Sector Potential Conflict Situations



After takeoff from its preferred runway, BRC926 periodically downlinks aircraft state information to the ATSP by air-ground data link, including current position, time, heading, altitude, and velocity vector, and atmospheric state measurements describing current wind, temperature and pressure.

Upon receipt of the initial aircraft airborne state report, the ATSP uplinks an atmospheric forecast to BRC926 describing the predicted meteorological state at 3D points along the ATSP-cleared trajectory. Prior to top of descent, ATSP uplinks an atmospheric prediction update and a trajectory intent interrogation. In response to the interrogation, the BRC926 FMS recalculates its forward trajectory and downlinks a trajectory intent describing the FMS-projected Mach/CAS speed and altitude descent profile, arrival runway threshold crossing speed, and the arrival runway and runway exit identifiers. ATSP automation processes the dynamically updated calibration information to refine the arrival airspace and runway utilization plan.

At key points (such as the top of climb), BRC926 downlinks a report of the FMS-determined aircraft weight. This information is used by the ATSP to calibrate its flight state data and modeling processes, enhancing trajectory prediction accuracy. BRC926 downlinks a request for an atmospheric prediction update. The ATSP responds by uplinking an atmospheric forecast describing the predicted meteorological state at the downstream waypoints along the current planned trajectory.

BRC926 continues to downlink aircraft state and atmospheric measurement periodically during climb, and will do so for the remainder of the trip.

The FMS-derived and AOC-provided calibration data are used by the ATSP automation to predict the departure trajectory as well as to construct alternative trajectories. The high fidelity trajectory prediction and assessment capability afforded by the calibration data, aircraft dynamics modeling, and conflict probe and trial planning DSTs, enables a controller to identify an efficient maneuver adjustment to BRC926 that avoids a potential conflict with an arrival flight to the airport. This approach permits the relaxation of a local altitude restriction that would require BRC926 to cross under the crossing and descending arrival traffic pattern (a procedural approach that results in a more costly deviation). ATSP automation uses the aircraft state reports to display accurate position, heading and speed data for BRC926, enhancing the controller's ability to monitor the trajectory dynamics and verify compliance with the clearance.

The air-ground and ground-ground data linked information improves the accuracy of the ATSP trajectory prediction models in comparison to the current baseline ATM system. ATSP automation processes the assembled calibration data (i.e., aircraft performance, pilot procedures, flight operating factors, aircraft state, intent and atmospheric parameters) to define alternative arrival trajectories to the user preferred and other qualifying runways.

BRC926's FMS uses the atmospheric prediction data and its database of local standard departure procedures to recalculate its projected trajectory based on its current ATM clearance. BRC926 downlinks a trajectory intent report describing the FMS-preferred speed and altitude profile and times and altitudes at downstream waypoints. The data linked information are used by the ATSP to enhance the trajectory prediction models that are supporting multi-sector probing for potential violations of aircraft minimum separation and local TFM spacing constraints along BRC926's intended trajectory.

Integration of Controller DST with Controller-Pilot Data Link

Once the controller has determined that a resolution maneuver is necessary for separation assurance and/or TFM conformance, the controller can use their DST capability to automatically load a resolution advisory into the data link system for communication to the pilot. The DST advisory is translated into a tactical ATC instruction/clearance and automatically data linked to the aircraft when approved by the controller.

Integration of Controller DST with FMS via Controller-Pilot Data Link

This level of air-ground integration enables the ATSP and FD to communicate trajectory-based restrictions, instructions, and requests.

In the case of an ATSP-determined resolution maneuver, this level of integration allows the ATSP to issue strategic trajectory-based instructions that require an FMS integrated with data link for the pilot to be accept and/or precisely fly complex trajectory-base solutions that would otherwise be too complex to communicate by voice or manual data link entry.

Alternatively, this level of integration also supports explicit negotiation of user-preferred trajectory changes.

The automated probing identifies down-sector TFM spacing violations that, according to ATSP DST advisories, could be resolved by an altitude diversion to BRC926. Instead of transmitting this resolution to the aircraft, the controller elects to uplink the relevant TFM spacing constraint information using automated procedures. The FMS determines that a speed reduction is a preferred fuel-efficient solution, and the pilot downlinks the corresponding trajectory change request. The controller probes this alternative for potential conflicts and TFM constraint violations, determines that it is acceptable, and approves the speed change by data link acknowledgement. The FMS and ATSP active trajectories are updated.

In those cases where the ATSP DST advisory is to be sent to the flight deck, the provisional trajectory plan is uplinked to the aircraft. As result of the ATSP assessment, BRC926 is issued a provisional plan to reduce cruise speed before top of descent without changing the top of descent location. The resulting trajectory is the most cost-effective alternative for the prevailing traffic situation. The FMS confirms the plan's acceptability, the pilot approves, and the clearance change negotiation is completed through routine data link transaction and data processing procedures. The ATSP provisional plan is converted to active status by the automation, and noted by the controller.

These air-ground data link transactions by BRC926 during cruise are repeated at trajectory change points, such as top of step climb and key turn points, as well as at occurrences of deviations from the intended trajectory. ATSP decision support tools continue to update trajectory predictions, perform trajectory probing, and display advisories and data to controllers.

Rare Nominal Modes: Rare nominal modes are defined as operation in conditions that stress the applicability of the concept. In general these are conditions in which anything changes quickly and/or unexpectedly. Examples are the following:

- Weather
- Large fronts which developed unexpectedly
- Fast moving fronts
- SUA unscheduled activation on short notice
- Traffic complexity developing quickly and not anticipated by traffic management
- An unusual increase in traffic volume

Failure Mode Scenarios: There are no currently identified failure mode scenarios that drive CE 6 concept development. If the ATSP CE 6 decision support tools fail, ATM operations revert to those of the current system. If a FD or AOC automation function fails, that operator or aircraft cannot participate in CE 6 services and the ATSP develops the most acceptable resolution given the available information.

7. Summary of Impacts

7.1 Operational Impacts

The following functional changes from the current NAS, expressed in terms of technology and infrastructure, are needed to support the concept. These are described in the areas of communications, navigation, surveillance, automation, weather, and traffic management.

Communications: Trajectory negotiation is facilitated through use of two-way air-ground data link between ATSP computer systems and the FMSs on the flight decks and two-way ground-ground data link between the ATSP and AOC computer systems. The AOC also provides trajectory planning data to the FD through air-ground data link. Calibration data are exchanged to support trajectory modeling and analysis, and negotiation data are exchanged to support trajectory adjustment. Calibration data exchanged between ATSP and FD systems include dynamic factors describing trajectory state and intent and atmospheric conditions. Calibration data exchanged between AOC and ATM systems generally include less-dynamic factors describing aircraft performance and flight operating procedures. Negotiation data exchanged between ATSP and FD systems describe trajectory preferences and constraints.

The data link communication message system is a critical element in integrating ATSP, FD and AOC operations and technologies in CE 6. The data link message set used for trajectory negotiation is designed to be in conformance with the data processing requirements of ASTP, FD and AOC automation. The data content and structure or these messages support the trajectory determination, prediction and assessment functions of FMS units and ATSP and AOC decision support tools.

Moreover, this concept is based on the integration of ATSP DST automation and FMS with data link to overcome the limitations of voice communications and manual data link interaction

Navigation: There are no new functional navigation requirements imposed by the CE 6 concept beyond those that are subjects of current development efforts of the aviation industry. GPS is certified as a means of navigation and supports the determination of accurate trajectory state information and accurate adherence to trajectory intent. The on-board navigation system has a Required Navigation Performance (RNP) level with sufficient accuracy to support trajectory negotiation applications.

Aircraft participating in CE 6 operations have advanced FMS units capable of accurately adhering to a planned position, altitude, and time-defined trajectories, including RTA applications. These advanced FMS units typically include a central flight management computer, airplane systems inputs of air data, inertial reference and engine sensor parameters, digital flight control computers, and a pilot interface consisting of electronic flight displays, mode control selection panel, and control display unit. The display system includes a primary flight display, a navigation display, an engine display, and the data link message display. FMS vertical profile planning programs compute crossing speeds, altitudes and times at downstream waypoints based on altitude and cost index selection parameters. The navigation database contains pre-specified routes, fixes, and arrival and departure procedures with altitude and speed constraints by waypoint. The FMS retains the active and provisional trajectories, which may be may be modified, exchanged, stored and retrieved. The active route provides guidance and situation information, and the provisional route enables review of proposed routing and profiles or FD-initiated trajectory changes.

Surveillance: Aircraft participating in CE 6 operations are equipped to transmit their state and intent information computed in the FMS. The ATSP surveillance function fuses the FMS-derived state information with that obtained from area radar.

Automation: CE 6 ATSP decision support tools support the following automation functions:

- Develop knowledge of state and intent of traffic
- Develop knowledge of atmospheric conditions
- Perform trajectory modeling
- Perform aircraft separation and TFM constraint violation probing and resolution
- Accept user preferences
- Provide interactive display interface for trajectory negotiation

These automation functions are supported by appropriate two-way data link between the ATSP, FD and AOC.

Weather: The ATSP provides accurate atmospheric modeling of winds aloft, temperature, pressure and turbulence conditions, and provides gridded and along-track atmospheric forecast information to aircraft. These data are updated regularly by down linking of wind and temperature measurements from participating aircraft.

Traffic Management: There are no changes required for strategic traffic management at the Command Center level. Local traffic management participates in setting the TFM constraints at the ATSP sector and facility level. Local TFM constraints include miles-in trail spacing, time-based metering, and altitude, speed, route and related procedural restrictions.

7.2 Organizational Impacts

To be determined

7.3 Impacts during Development

DAG-TM CE 6 is at a very early stage of development. As such, it is difficult to determine the impacts on the user, acquirer, and maintenance organizations during development. It is however required that FAA air traffic controllers participate in the development process during demonstration and test phases. Significant impact are however expected on the user, developer, and on the ATM system personnel during development because of the negotiation process that will be caused by CE 6.

Although this concept element represents a more conservative approach than Free Maneuvering (CE 5), it does present several challenging issues. These include, but are not limited to, the following.

Foremost is the need to transform ATSP roles and procedures for controlling traffic across sectors. Today's operations are "sector-oriented" whereby each sector focuses on the protection of its own airspace. Congestion-related problems, such as metering conformance to a downstream fix, are managed in a piecemeal fashion across sectors using a series of tactical trajectory deviations. The goal is to develop ATSP DST tools and procedures to facilitate "trajectory-oriented" operations whereby ATSP control actions are formulated to nominally resolve problems in downstream sectors. This parallels FD operations that use the FMS to nominally plan a continuous trajectory solution that meets the flight's constraints.

Other challenges include the technological integration of data link with FD and ATSP automation, the human factors necessary to utilize such integrated systems (e.g., automation displays and interfaces), and the system engineering needed to merge and manage communications, navigation, and surveillance data.

8. Analysis of the Proposed System

8.1 Summary of Advantages

En route trajectory negotiation improves the performance of FMS and ATM automation and enhances situation awareness, resulting in improved flight operating efficiency, reduced workload and associated safety impacts.

Safety in separation assurance for all aircraft may be increased by reductions in the rate of ATSP conflict-probe missed alerts, resulting from improved trajectory-prediction performance (realized through information sharing). Improved accuracy will also reduce the rate of false alerts and reduce unnecessary deviations. When conflicts do occur, improved prediction accuracy will reduce resolution deviations by increasing the effective time horizon for detection, and allowing the ATSP to reduce the buffers used to ensure separation in the presence of uncertainty.

ATSP separation assurance workload is reduced through a reduction in the rate of conflict probe false alerts and missed alerts. Additional ATSP workload benefits stem from the integration of DST automation, data link, and FMS. DST advisories help to automatically compose messages by providing the ATSP with clearance advisories that can be accepted or modified easily. In a complementary fashion, data link communications automatically provide the ATSP DST automation with a digital record of ATSP instructions. Such data allows the DST to automatically adapt advisories to reflect actual control actions. Moreover, integration enables the ATSP to issue precise trajectory-based instructions and delegate greater trajectory-conformance responsibility to the FD. The corresponding net increase in ATSP productivity may be translated into greater throughput and/or increased opportunity for ATSP consideration of user-preferred trajectory change requests.

User flexibility is increased in that ATSP deviations for conflict resolution and TFM conformance better accommodate the user's operational preferences. By accounting for NAS operational constraints (e.g., user preferred trajectory planning for conformance with TFM metering restrictions (e.g., RTA)), the appropriately equipped user is able to formulate clearance change requests that require significantly less ATSP workload to analyze, accommodate, and coordinate (with other sectors/facilities). Users are able to fly their preferred trajectories more frequently.

In addition to the potential benefit mechanisms described above, this concept element also offers an evolutionary development stage for transitioning to the more advanced concept element of Free Maneuvering. Starting with a relatively moderate level of airborne equipage (4D FMS integrated with data link) the addition of CDTI and basic airborne CD&R capabilities would enable users to formulate more "intelligent" trajectory preferences. This could further reduce ATSP workload and increase the ATSP accommodation of user-preferred trajectories. Initial airborne CD&R capabilities could provide an operational foundation for the eventual certification of critical systems necessary for Free Maneuvering.

Various aspects of the potential benefits are summarized below according to the following categories: capacity, flexibility, efficiency, predictability, access, environment, and safety. The results of an on-going study (Reference 20) have been liberally used to categorize and amplify on these benefits.

Capacity

CE 6 contributes to increased en route capacity. In addition this, some benefits (e.g., improved flow rate conformance) can lead to increased airport throughput.

- **Decreased separation buffers -** CE 6 establishes a means to reduce the unnecessary separation buffers. CE 6 assists in trajectory planning and negotiation by providing an automated method to exchange continual updates of aircraft data, air traffic data, and atmospheric data between the flight deck (of equipped aircraft) and the ATSP. Through this automation, the uncertainties in the data used for trajectory calculations are reduced, resulting in the ATSP being able to reduce the separation buffers applied for these unknowns. As the buffers are reduced, aircraft can be "packed" closer together yielding increases in capacity.
- **Reduction in False Alerts -** CE 6 produces an increase in the accuracy of the current and forecast trajectories. With the increased accuracy of trajectories, the discrepancies found between actual and predicted trajectories are reduced or eliminated and actual conflict detection is improved. As a result, false and missed conflict alerts are reduced, as well as inappropriate resolution advisories. The reduction in false alerts will eliminate unnecessary flight path deviations and will contribute to a reduction in ATSP workload. The reduction in missed alerts will reduce the magnitude of deviations (by removing the need for delayed corrective action). By decreasing the number and magnitude of deviations, more airspace resources are available and capacity is increased.
- **Reduction in Excessive Deviations -** Under CE 6, the magnitude of separation-induced deviations will be reduced for several reasons:
    - A reduction in false alerts.
    - A decrease in the resolution buffers.
    - An increase in look-ahead time allowed by improved trajectory prediction.

  The decrease in resolution buffers is distinct from the decrease in the detection buffers. Given current uncertainties, the ATSP will attempt to separate aircraft using "fire and forget" maneuvers to avoid having to correct for uncertainties. Naturally, this effect will depend on the controller's task loading, but one would expect an *average* buffer to result. A further reduction in the buffer can be obtained if the task loading has been reduced sufficiently to allow the ATSP to continually adjust resolution maneuvers.

  The reduction in trajectory perturbations decreases the utilization of airspace resources, thereby potentially increasing capacity.
- **Improved Schedule and Sequence Plans -** Improvements in information available to the ATSP allow traffic management functions to develop better aircraft sequence and schedule plans that more fully use available airspace and airport capacity. The improved information not only allows the development of improved plans, but the

improved execution of those plans. As confidence develops in the execution, tolerances can be tightened.

Since ATM decision support tools must operate in an uncertain environment, they must be robust to typical disturbances. As the uncertainty is reduced due to improved information, options previously discarded for robustness considerations become available.

- **Improved Flow Rate Conformance -** The improved trajectory prediction capability of decision support tools allows improved assignments of RTAs and maneuvers. These result in improved flow rate conformance (measured through a reduction in the arrival time error at the metering fix). This increased flow rate conformance yields decreases in missed slots. These slots could refer to arrival slots in the case of arrival fix metering, or downstream metering slots in the case of en-route fix metering. Note that this effect is distinct from the effect of the decrease in the separation buffers.
- **Increased ATSP Productivity -** Increased ATSP productivity can improve capacity and throughput through several mechanisms:
  - Reduced workload through the automatic loading of ATC instructions from the ATSP DST automation directly into the data link system. This reduces the controller task loading for interacting with the two systems simultaneously and having to manually input ATC instructions into the data link system for communication to the pilot.
  - Reduced workload through the use of strategic “trajectory-based” instructions that allow the controller to delegate a trajectory resolution to the pilot to execute precisely using their FMS.
  - Reduce the occurrences of bottlenecks for both en route flows and flows that transition from en route to terminal airspace.
  - Reduce the need for traffic management restrictions in Center airspace.

In the first mechanism, bottlenecks often result when a sector becomes saturated (i.e., overloaded) and the controller’s top priority of providing separation assurance overrides secondary objectives of managing traffic flows, meeting crossing restrictions, or considering user requests. A reduction in controller workload, not just for separation assurance, but across all tasks, essentially enables an increase in productivity. Increased productivity enables the controller to continue to perform secondary tasks under higher traffic loading conditions. This, in turn, provides the downstream controllers with well-managed traffic flows and reduced workload, which increases their productivity as well.

The second mechanism (reducing the need for traffic management restrictions) is a by-product of increased controller productivity. Increased controller productivity would enable sector saturation thresholds to be increased (i.e., projections of traffic loading to reach higher levels), which would reduce the need for traffic management restrictions and increase the capacity of individual sectors. One of the goals of CE 6 is to improve the human performance of the controllers so that sector saturation is less likely to occur.

CE 6 also offers potential pilot productivity increases (reduction in workload) through autoloading/integration, but we assume that such airborne benefits support the pilot's role in using the FMS and data link to fly more precisely in response to more complex instructions. Thus we are not measuring pilot productivity or modeling pilot workload in this study; rather we assume that this benefit supports the sort of operations that will increase ATSP productivity.

Flexibility

Flexibility is defined as the ability of users to optimize operations, based on their objectives (e.g., a business objective, an environmental objective, a safety objective) and constraints. The benefit that is achieved through the provision of the flexibility will depend in large part on the objective of the operator. The following benefit mechanisms related to flexibility have been identified for CE 6:

- **Accommodation of User Preferences -** CE 6 provides the mechanisms for the flight crew and/or AOC to receive system state data, such as TFM constraints or atmospheric forecasts. Through the use of the FMS and the up-linked data, the flight crew can then compute their preferred trajectory and present the preferences to the ATSP for consideration. The flight crew (in consultation with their supporting AOC) can compute a trajectory that is acceptable, conflict-free, and fulfills the requirements of the flight crew and airline operations (e.g., time savings).
- **User-determined Flight Prioritization -** Under CE 6, operators are provided with the information necessary to re-plan a flight with a good chance of being accepted by the ATSP. This benefit will be constrained by the requirement that flights be subject to meeting TFM constraints under CE 6. The ability to re-plan each individual flight allows operators more flexibility in managing entire fleets of aircraft. This flexibility will translate to efficiency gains as operators capitalize on the flexibility.
- **ATSP Airspace Use Flexibility -** Under CE 6, the ATSP may modify the structure of the airspace dynamically. This ATSP flexibility, when combined with negotiation with the flight deck allows trajectories to be selected that best capitalize on changing atmospheric conditions.
- **Increased Surface Operations Flexibility -** When provided with improved arrival time predictability, operators have more flexibility in managing their surface operations. Consider two situations, one in which operators have a half-hour variance in arrival time, and another in which operators have perfect knowledge. The operators with perfect knowledge will have more options for surface operations (e.g., gate assignment, ability to handle perturbations).

Efficiency

Increases in efficiency are those changes that will lead to lower operating costs. Like capacity, gains in efficiency will be the result of a combination of factors to yield a reduction in delays, improvements in fuel consumption, reductions in scheduled time, increase in number of potential operations, decrease in direct operating costs and increases in gross domestic product.

Certain efficiency gains will lead to improvements in system performance such as a reduction in the number of missed and false alerts, an improvement in the time required for trajectory changes, and a decrease in the number of mistaken data incidents. The following benefit mechanisms related to efficiency have been identified for CE 6:

- **Arrival Delay Inefficiencies Minimized -** Arrival flights incur delays during rush periods at congested airports due to short-term imbalances in capacity and demand. TMA allows a greater fraction of the delay incurred by arriving aircraft to be absorbed in the en route airspace while still maintaining pressure on the runways. CE 6 allows TMA to decrease the TRACON delay allocation by increasing the accuracy of delivery at the metering fix beyond that obtained currently. By decreasing the TRACON delay allocation, necessary delays required for runway contention can be absorbed by flights in en route airspace, thereby consuming less fuel for the same delay.
- **Improved Conflict Resolutions -** Under CE 6, the use of automated data exchange increases the accuracy of prediction capabilities. With more precise predictions, the knowledge of potential conflicts and resolution options is improved leading to fewer unnecessary maneuvers, smaller maneuvers to confidently resolve conflicts, and earlier maneuvers leading to more options available.
- The above combination of options lead to conflict resolution maneuvers that are more efficient in terms of both time and fuel consumption.
- **Decreased Separation Buffers -** In a manner similar to the improved conflict resolution, the reduction in the ATSP-imposed separation buffers leads to a decrease in the magnitude and number of maneuvers required for separation. This reduction provides increases in efficiency through reduced fuel consumption and delays.
- **Efficiency Gains Through Flexibility -** By capitalizing on the flexibility offered to the flight, users are capable of defining and obtaining trajectories that minimize their operational costs by striking a balance between fuel and time costs. User preferred trajectories include path, altitude and speed schedules. This reduction in operational costs represents a gain in efficiency to each user of the system.

  CE 6, by providing data to the flight deck such as TFM constraints, and more accurate wind data, the flight deck is in a position to make intelligent choices regarding trajectory changes. The flexibility offered to the flight deck is only useful if this information is passed to the flight deck.
- **Increased Acceptable Trajectory Changes -** When provided with more accurate information and more information on user preferences, the ATSP can provide the flight with trajectory changes that are commensurate with user preferences. This is conditional on the ATSP having the DST available to compute trajectories in accordance with the preferences. This benefit ensures that ATSP-provided trajectory changes allow each user to obtain efficient trajectory modifications that are consistent with their operational cost structure.
- **Efficiency Gains Through Predictability -** Increases in predictability provided by CE 6 allow operators to modify their flight schedule. Current practice results in flight

schedule “padding” in order to obtain certain on-time arrival performance. While the mean delay will contribute to this padding, higher variance in delays can also contribute to the required level of padding. For certain critical flights into hubs, arrival performance can have a significant downstream effect, for these flights the variance is dealt with by padding the schedule to provide a desired on-time arrival probability. By providing a mechanism by which schedule padding can be reduced, schedule-borne costs can be reduced (e.g., flight crew regular time) and aircraft utilization rates may be increased.

- **More Efficient Profiles -** Under current operations, climbing flights are provided a sequence of altitude clearances during climb. Usually, controllers will provide a new altitude clearance prior to the aircraft leveling-off at the interim altitude. However, sometimes the flight must level-off at the interim altitude for a variety of reasons:
  - A potential conflict exists at a higher altitude.
  - The controller is busy with another task and cannot issue the clearance in time.
  - The aircraft has climbed faster than the controller expected, and the controller maintains the aircraft at the lower altitude to maintain a flow structure.
  - Under CE 6, the ATSP will be provided with DSTs that will assist in the development of conflict-free trajectories conforming to stated user-preferences. Furthermore, controller workload is expected to be decreased, thereby decreasing the number of times the second reason exists.
- **Efficiency Gains Through Capacity -** As capacity of the system is increased, all aircraft will encounter a reduction in the delays at any given demand level. This reduction in delays can lead to direct benefits (reduced fuel consumption and time of flight), multiplicative effects through delay multipliers, and schedule changes due to a reduction in the mean delay.

<u>Access</u>

- The following potential benefit mechanisms have been identified for CE 6:
- Improved sequence and schedule planning leads to improved access to non-scheduled users.
- Improved information availability may increase access to restricted airspace.
- Improved information availability may lead to dynamic restrictions and increased airspace access.
- Decreased airline flight operating costs due to improved trajectory choices could lead to greater access by the flying public.
- Increased airspace accessibility due to reduction in separation buffers.

<u>Environment</u>

The following potential benefit mechanisms have been qualitatively identified for CE 6:

- The creation of more fuel-efficient trajectories leads to a reduction of emissions dispersed in general and at lower altitudes.
- Reduction in noise exposure occurs when the terminal delay can be shifted and absorbed at higher altitudes, which is most cost effective for the flight operations.
- Environmental benefits would be measured as reductions in nitrogen oxide, hydrocarbons and carbon dioxide emissions. Noise benefits would be measured through changes in effective perceived noise level contours.

Safety

The following potential benefit mechanisms have been qualitatively identified for CE 6:

- Improved trajectory prediction accuracy leads to improved conflict detection and a reduction in missed and false alerts. This reduces the likelihood of the ATSP's failure to recognize potential violations of separation.
- Situational awareness is improved due to the automated and integrated system described in which the NAS state data is uplinked to the flight crew and the flight data are down linked to the ATSP.
- Datalink and DSTs improve advisory performance, which could provide increased safety during weather situations such as avoidance of en route thunderstorms and severe turbulence..
- Automated data exchange and equipment to assist with calculations and monitoring, and issuance of instructions/clearances could reduce potential sources of human error.
- Allowing aircraft to compute preferred trajectories away from areas of moderate turbulence, and transmit their preference to the ATSP for consideration, may decrease the occurrence of turbulence-related injuries
- Improvements in conflict probe missed alerts (related to safety) could be measured directly. The safety benefit of "removal of human error" will scale with the original human errors being removed. Statistics on the level of these errors could be used as a surrogate.

8.2 Summary of Disadvantages/Limitations

DAG-TM CE 6 will require the ground system be capable of performing CD&R beyond the boundaries of the sectors within a Center and beyond the boundaries of the Center. In addition the airborne and the ground-based CD&R systems should be compatible, i.e., they should not give contradictory results. Other disadvantages/limitations will become apparent as the CE 6 research program progresses.

8.3 Alternatives and Tradeoffs Considered

CE 6 is under initial development as a concept. The key issues concern refinement and validation of the basic concept and development of the details. Validation of the concept should involve operations staff at an early stage to confirm the concept is proceeding in the proper direction.

9. Notes

Acronyms

4D	Four Dimensional
AATT	Advanced Air Transportation Technologies
AOC	Airline Operations Center
ARTS	Automated Radar Terminal System
ASAS	Airborne Separation Assurance System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATSP	Air Traffic Service Provider
A/C	Aircraft
CDTI	Cockpit Display of Traffic Information
CD&R	Conflict Detection and Resolution
CE	Concept Element
CHI	Computer Human Interface
CNS	Communications, Navigation, and Surveillance
CPDLC	Controller Pilot Data Link Communications
CTAS	Center-TRACON Automation System
DAG	Distributed Air/Ground
DST	Decision Support Tool
D-Side	Data controller
EDA	En Route Descent Advisor
FAA	Federal Aviation Administration
FD	Flight Deck
FMS	Flight Management System
GPS	Global Positioning System
HCS	Host Computer System
IFR	Instrument Flight Rules
ITWS	Integrated Terminal Weather System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRP	National Route Program
OCD	Operational Concept Description
ORD	Chicago O’Hare International Airport
PARR	Problem Analysis Resolution and Ranking Tool
PFAST	Passive Final Approach Spacing Tool
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTCA	RTCA, Inc.
R-Side	Radar controller
RUC	Rapid Update Cycle
RVSM	Reduced Vertical Separation Minima
SSR	Secondary Surveillance Radar
SUA	Special Use Airspace

TFM	Traffic Flow Management
TM	Traffic Management
TMA	Traffic Management Advisor
TRACON	Terminal Radar Control
TRL	Technology Readiness Level
TW	Terminal Weather
UPT	User Preferred Trajectory
URET	User Request Evaluation Tool
ZDV	Denver Center